The

VIKING

mission to mars

NASA SP-334

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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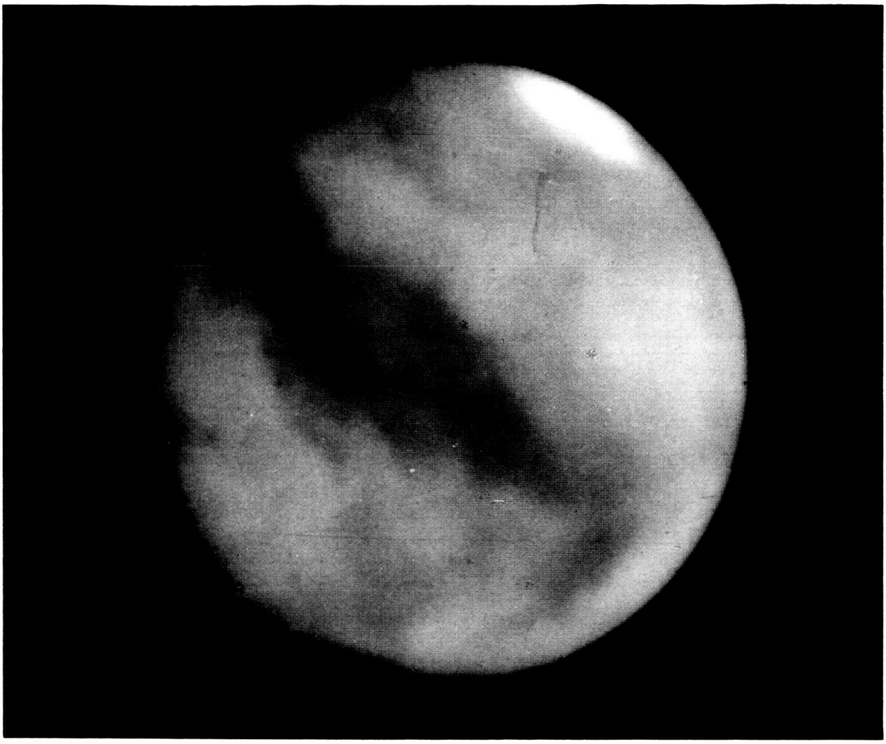

Only through comparative studies of other planets and their evolution will man truly begin to understand the forces which shaped his own being and the world in which he lives.

JOHN E. NAUGLE
Deputy Associate Administrator

NASA SP-334

The VIKING mission to mars

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Scientific and Technical Information Office 1974
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

Foreword

This monograph describes the National Aeronautics and Space Administration's program to explore the planet that most nearly resembles the Earth. Americans have taken many giant steps for all mankind since 1776, but few as potentially momentous as the search for life on the surface of Mars that the Vikings are scheduled to begin in 1976.

The recent Mariner flights by and around Mars have yielded photographic and other data packed with surprises for scientists. The Soviet Union has also embarked on an extensive program to study Mars' surface. From the Viking instruments that are being readied now for use on the surface and in orbit around Mars, much more will be learned about the nature of the planet, possible origins of life, and the possible fate of our own environment.

In this brief account of the Viking mission to Mars, Mr. Corliss has endeavored to describe it in ways understandable to everyone.

EDGAR M. CORTRIGHT
Director
Langley Research Center

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Chapter 1
The Purpose of Planetary Exploration

From the Great Pyramid to Palomar, man has always searched the skies for clues to his destiny. Down the centuries the bright, wandering orbs of the planets have captured his imagination. At first, he peopled those spheres with his ancient gods and, later, with the exotic creatures of science fiction. Although the Sun's planets are devoid of those fanciful beings, they boast something much more valuable: The keys to understanding our Earth, its geological past, and how its variegated cargo of life originated and evolved.

The planets of the solar system probably had a common origin. The current view holds that all were formed by "accretion," as gravity pulled dust and rocky debris into the spherical conglomerations of matter we now call planets. Despite their similar births, each planet is different in character. Earth teems with life; Jupiter is massive with a thick and colorful atmosphere; Mercury is small with little atmosphere and baked by the nearby Sun; while Mars, the most Earth-like of all the planets, is a dry, windblown, cold desert. Their different chemistries, geologies, and meteorologies derive from their different masses and varying distances from the Sun. This diversity alone makes planetary exploration worthwhile.

What the planets can tell us about life is possibly even more important. Earth, to be sure, harbors abundant life in a relatively thin biosphere only a few miles thick but is unique among the denizens of the solar system in this regard. Data gathered from outer space—the amino acids detected in meteorites and the observed spectra of water, ammonia, and organic chemicals in interstellar space—suggest that the chemical building blocks of life are universal. Life may be an integral, perhaps inevitable, part of the unfolding evolution of the universe. Very likely some of the precursors of life exist somewhere on our eight sister planets or their several dozen assorted moons. Somewhere in the solar system, chemical evolution may have taken that one critical additional step into the realm of life, just as it did some 3.5 to 4 billion years ago on Earth.

By exploring the other solar system planets and their satellites, we should be able to study the various stages of chemical and, hopefully, biological evolution. Thereby, scientists can gain insight into the proc-

esses leading from simple molecules to man. Valuable as this detailed insight would be, just one look at that part of the drama which reveals some form of "other life" would make space exploration worthwhile.

Recognizing that many scientific secrets still lie hidden throughout the solar system, NASA has a program of solar system exploration aimed at answering the following questions:

(1) How did our solar system form and evolve?
(2) How did life originate and evolve?
(3) What are the processes that shape our terrestrial environment?

Our astronauts have begun detailed exploration of the Moon, but we have sent only a few instrumented spacecraft past or into orbit around the other planets. Among the other planets, Mars is the most potentially rewarding as an astronautical objective, especially in terms of the second question. It is neither too hot nor too cold; it possesses carbon dioxide and some water. Life could exist there, and scientists are eager to send their instruments down to the Martian surface.

The possibility of Martian life—extinct, extant, or future—is the target of the Viking program that is described in detail in this publication. The two Viking spacecraft, to be launched in 1975, will be Orbiter-Lander combinations. The Orbiters will contribute to the science objectives of the mission by taking photographs and spectra over large regions of the planet. The Landers will make *in situ* atmospheric and meteorological measurements during descent and while on the surface. Once safely landed, various other instruments will analyze the soil for organic and inorganic compounds and try to detect biological activity.

Viking is a challenging program to explore the surface of a planet millions of miles away. From the information in the stream of radio signals beamed back to Earth across that immense void, we hope to learn more about Earth through the study of the differences and similarities of the planets and, possibly, to hear first signals announcing the discovery of extraterrestrial life.

Chapter 2
Viking's Target: Mars

The Red Planet Through the Telescope

Mars is the third smallest planet of our solar system. Its diameter is scarcely half that of Earth and its mass is only one-tenth that of our globe. Yet, of all the planets that circle the Sun, Mars seems most like Earth. Its year is twice ours—687 days—but the Martian day is almost exactly the same—24 hours, 37 minutes, and 23 seconds. Mars has a thin atmosphere which supports a few clouds and fierce duststorms. Because the axis of Mars is tilted at 25° to the plane of its orbit, it has seasons that superficially seem like those on Earth. When spring comes to the northern hemisphere of Mars, its northern polar cap recedes while the southern cap grows. As the white northern cap shrinks, a wave of darkening appears to sweep south toward the equator as if Sun-released moisture were reviving dormant vegetation. Little wonder that some early astronomers reckoned Mars a second Earth! Scores of science fiction stories portrayed their heroes striding across the red sands of Mars, while Phobos and Deimos, the two tiny moons, raced overhead.

Many facts about Mars can be verified through the telescope; but the older visions of Earth-like springtimes, greening vegetation, and a biosphere like our own are unwarranted extrapolations from them. Mars is still a mysterious planet. Each new phase of scientific exploration has changed our picture of it substantially. Telescope, spectroscope, flyby spacecraft, and orbiting spacecraft have in their turns revolutionized our concept of Mars.

When an astronomer trains his telescope on Mars, he sees a fuzzy reddish sphere capped in white at both poles. There are pronounced light and dark areas and, when the Earth's turbulent atmosphere holds still for a moment, fine details seem to crystallize. (See frontispiece.) It was during such moments of "good seeing" that Giovanni Schiaparelli saw and drew his famous "canali," or channels, when Earth and Mars were separated by a distance of less than 35 million miles during the opposition of 1877. Today we know there are no canals on Mars, but we still are not able to study details of the Martian surface through a telescope.

Spectroscopic studies of Mars began in 1862 when the English astronomer William Huggins first applied that technique. When a prism, or ruled grating spreads the light from Mars out into a spectrum, dark absorption bands can help to identify the atmosphere's constituents, but for more than 80 years astronomers have struggled with their spectroscopes with scant results. The atmosphere of Mars is so thin that absorption bands, if present, were difficult to discern. Finally, in 1947, Gerard P. Kuiper positively identified several infrared absorption bands due to carbon dioxide. Despite this evidence, carbon dioxide was assumed to be a minor constituent in comparison to nitrogen, even though nitrogen had not been detected. This assumption, based on analogy with the Earth's atmosphere, was proven incorrect in the 1960's. Carbon dioxide is now known to make up most of the Martian atmosphere. This turnabout and others to follow illustrate the difficulty of doing planetary research at distances of 35 million miles, the closest Mars ever gets to Earth.

The brilliant polar caps of Mars were initially assumed to be ice or at least a layer of hoarfrost (again in analogy with Earth). Water vapor was therefore expected to appear in Martian spectrograms. But the characteristic infrared absorption bands of Martian water vapor, if they existed, were masked by water vapor in Earth's atmosphere above the telescope. Finally, in 1963, scientists definitely detected Martian water vapor bands by utilizing the Doppler shift caused by the relative motion of Mars and Earth.

A rough idea of the Martian surface temperature was acquired by measuring the heat radiation emitted (not reflected) by the planet in the infrared portion of the spectrum. Temperature measurements made in 1922 indicated that Mars was a very cold planet, but not completely hostile to life as we know it. Refined techniques have led to the conclusion that shortly after midday, surface temperatures on the equator can rise to at least 25° C (77° F). (See table 1.)

The first indications that life might exist on Mars came in 1956 and 1958 when W. M. Sinton observed distinct absorption bands at 3.43, 3.54, and 3.69 micrometers in light reflected from the dark areas of Mars. Since carbon-hydrogen bonds in organic compounds display similar bands, some sort of life, probably vegetation, might occur in the dark areas. Like the canals a half century earlier, Sinton's bands, as they were called, led many to conclude that Mars indeed did support life.

A rude awakening came in 1965 when two of Sinton's bands were identified as absorption bands of the rare molecule hydrogen deuterium oxide, HDO (a type of heavy water), in Earth's atmosphere. Once again the limitations of Earth-bound astronomy had been emphasized. By this time, however, a spacecraft was on its way to Mars to observe the planet from an incomparably better vantage point as it flew past.

TABLE 1.—*Physical Properties of the Planet Mars*

Property	Value	Equivalent value in: Metric system	Equivalent value in: English system	Value for Earth in English system
Mean sidereal year,[a] days	686.98	------	------	365.24
Mean distance from Sun,[a] astronomical units	1.52	217.94×10^6 (kilometers)	141.64×10^6 (miles)	93×10^6 (miles)
Distance at perihelion,[a] astronomical units	1.38	206.66×10^6 (kilometers)	128.41×10^6 (miles)	91.40×10^6 (miles)
Distance at aphelion,[a] astronomical units	1.67	249.22×10^6 (kilometers)	154.86×10^6 (miles)	94.51×10^6 (miles)
Close approach (opposition),[a] astronomical units:				
August 12, 1971	0.38	56.20×10^6 (kilometers)	34.92×10^6 (miles)	
October 17, 1973	0.44	65.22×10^6 (kilometers)	40.53×10^6 (miles)	
December 8, 1975	0.57	84.60×10^6 (kilometers)	52.57×10^6 (miles)	
January 19, 1978	0.65	97.72×10^6 (kilometers)	60.72×10^6 (miles)	
February 26, 1980	0.68	101.32×10^6 (kilometers)	62.96×10^6 (miles)	
Inclination,[a] degrees	24.94	------	------	23.45
Mean equatorial diameter,[b] kilometers	6786	------	4217 (miles)	7926.4 (miles)
Mean polar diameter,[b] kilometers	6751	------	4195	7899.8
Mass,[b] grams	6.18×10^{26}	------	1.36×10^{24} (pounds)	13.18×10^{24}
Mean density,[b] grams per cubic centimeter	3.945	------	0.146 (pounds per cubic inch)	0.199 (pounds per cubic inch)
Magnetic field at surface,[b] gauss	$<4 \times 10^{-4}$	------	------	0.32
Length of day,[b] hours and minutes	24^h37^m	------	------	24^h
Mean solar irradiance,[b] watts per square centimeter.	0.058	------	------	0.139
Atmospheric pressure,[b] millibars	5.3	5.3×10^3 (dynes per square centimeter)	0.077 (pounds per square inch)	14.696 (pounds per square inch)
Atmospheric composition [b]	CO_2 ~100%			0.003%
	N_2 Trace			78.0
	H_2O Trace			0.001–0.028
	O_2 Trace			20.9
	Ar Trace			0.009
	CO Trace			Trace

[a] Data from ref. 1.
[b] Data from ref. 2.

TABLE 2.—*Summary of Mariner Flights to Mars*

Spacecraft	Launch date	Spacecraft weight, kilograms (pounds)	Encounter date	Remarks
Mariner 3	Nov. 5, 1964	262 (575)	----------	In solar orbit (shroud failure precluded Mars flyby).
Mariner 4	Nov. 28, 1964	262 (575)	July 15, 1965	Closest approach: 9800 kilometers (6140 miles).
Mariner 6	Feb. 24, 1969	414 (910)	July 31, 1969	Closest approach: 3400 kilometers (2131 miles).
Mariner 7	Mar. 27, 1969	414 (910)	Aug. 5, 1969	Closest approach: 3400 kilometers (2131 miles).
Mariner 8	May 8, 1971	1000 (2200)	----------	Launch vehicle failure.
Mariner 9	May 30, 1971	978 (2150)	Nov. 13, 1971	In Martian orbit.

The First Mariners

Mariner 4 flew past Mars on July 15, 1965, at a distance of 9800 km (6140 miles), snapping 22 pictures of the planet (table 2). To nearly everyone's surprise, the pictures revealed a heavily cratered surface like that of the Moon (fig. 1). Furthermore, the craters showed little evidence of erosion, suggesting that wind and water had scarcely touched the surface during the geological eons. Even though Mariner 4 had photographed only about 1 percent of the planet's surface (fig. 2) and from 9800 kilometers, the scientific interest in Mars as an abode of life quickly wavered. Mariner 4 suggested that Mars was geologically and biologically dead. To make the case for Martian life even worse, the Mariner 4 magnetometer radioed back that there was little or no magnetic field around the planet. With no magnetic field and only a very thin atmosphere to shield the surface from charged particles (and without atmospheric ozone to absorb ultraviolet radiation), life on Mars seemed unlikely indeed.

The conclusion was premature. From several thousand kilometers out, Earth also appears lifeless. Additionally, Mariner 4 photographed only a narrow strip of Mars. What did the other 99 percent look like?

Mariners 6 and 7 flew past Mars in the summer of 1969. In addition to cameras, they carried infrared and ultraviolet instruments to analyze the Martian atmosphere and surface. Again, photos of the surface showed many craters strewn across the planet's surface, but not at random. The 202 pictures (covering 20 times the area shown by Mariner 4) revealed two unexpected features: chaotic terrain composed of jum-

bled ridges and valleys unlike anything found on the Earth or Moon (fig. 3) and wide expanses of featureless terrain where craters had been somehow eroded (fig. 4). Mars had obviously been geologically active in the past and possessed its own evolutionary history.

The camera eyes of Mariners 6 and 7 saw no canals, but where canals were thought to be, the closeup photos revealed alinements of dark-floored craters and diffuse dark patches. Some of the alinements may be random but others probably have geological significance. Pictures taken over the southern polar cap indicated a thin layer of snow which infrared spectra suggest is mostly frozen carbon dioxide (fig. 5). The bulk of the thin atmosphere also seems to be carbon dioxide, with some water but little or no nitrogen. Atmospheric pressures were confirmed to be very low, about 6 millibars, compared to about 1000 millibars on Earth. Mars was thus found to be a unique member of the solar system.

The Orbiter Phase

Collectively, Mariners 4, 6, and 7 photographed only about 10 percent of the surface of Mars as they cruised past and went into orbits about the Sun. Only a long-lived picture-taking Martian satellite could provide a complete photographic map of Mars. This was the task of Mariner 9, which was inserted into Martian orbit on November 13, 1971.

A planetwide duststorm concealed most of the surface when Mariner 9 arrived at its destination. It was still possible, however, to make measurements of the upper atmosphere; and a spacecraft camera caught the two moons, Phobos and Deimos, in its field of view, revealing them as irregular, cratered chunks of rock (fig. 6). In addition, infrared spectrograms of the dust itself showed it to be similar in composition to surface rocks on Earth. To geologists this indicated that the lighter materials had risen to the surface while Mars was still molten, as probably happened when Earth was evolving.

As the duststorm slowly subsided in early 1972, Mariner 9 began sending back thousands of high-quality pictures of the surface. This detailed, comprehensive look at Mars revealed several things that telescopes could not show us and that had been missed by previous Mariners.

One of the most exciting discoveries was clear-cut evidence of fluid erosion. A meandering "riverbed" (fig. 7) and braided channels were photographed. Except for the nearby craters, such scenes might have been shot by satellites over the American Southwest. Equally extraordinary were pits and slumps (fig. 8) resembling ice-formed features in Earth's polar regions. Furthermore, the region around the southern polar cap proved to be extensively eroded as if by glacial action. Mars might have had an appreciable hydrosphere within the past 100 million years with accompanying glaciation and river erosion.

To heighten the resemblance to Earth, Mars has many volcanoes.

Nix Olympica (fig. 9), the largest observed in the solar system, is 500 kilometers (310 miles) wide at its base. The sea-covered foundation of Mauna Loa, Earth's largest volcanic formation, is only about half this breadth. Mars also has vast canyon lands (fig. 10). One great "rift valley" is 121 kilometers (75 miles) wide and almost 6½ kilometers (4 miles) deep, far greater than our Grand Canyon. Geologists see this as a great crack in the Martian surface where crustal plates are pulling apart, much as they are along the deep fault that bisects Iceland. Like Earth, Mars seeems to have two kinds of surface: recent, relatively featureless terrain like Earth's sea bottoms and old, well-cratered regions similar to terrestrial continents.

Will the similarities end with geology? Perhaps somewhere on Mars near the warmth of a volcano or a similar favorable niche, life may have survived from warmer, wetter days. Or Martian life may be prospering in its present environment. For it is now believed, based on the Mariner 9 results, that the polar caps do contain a frozen-water deposit below an overlay of frozen carbon dioxide, and that at the fringes of the southernmost extremes of the northern cap temperature and pressure conditions exist for a short period of the Martian year which would allow even certain forms of terrestrial life to assimilate liquid water—or Mars may truly be lifeless. We do not know.

FIGURE 1.—In 1965 Mariner 4 sent back puzzling views of Mars.

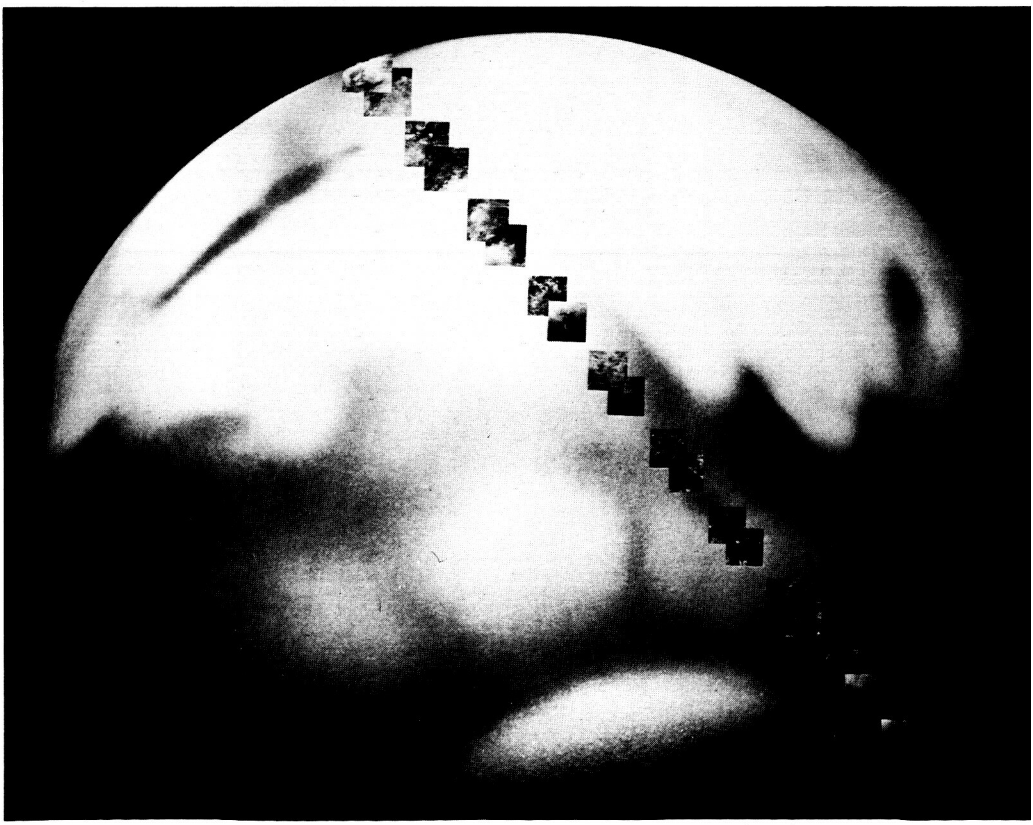


FIGURE 2.—Mariner 4 photographed 22 small parts of surface.

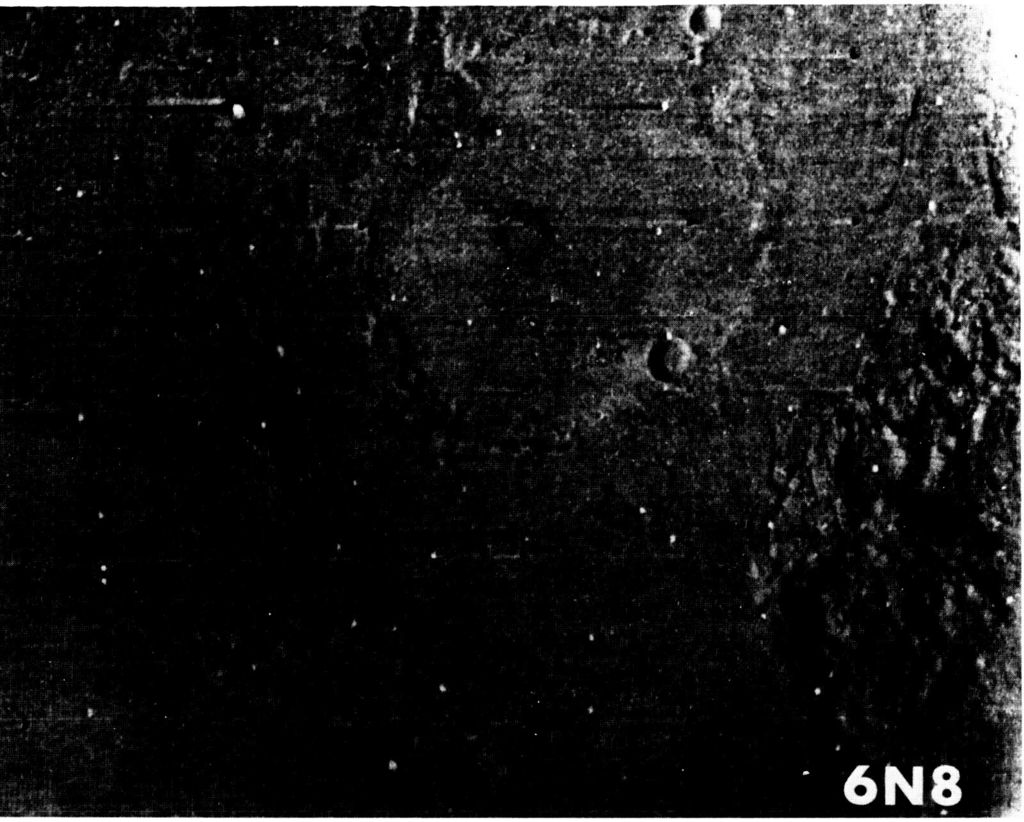


FIGURE 3.—Chaotic terrain was noted by Mariner 6 in 1969.

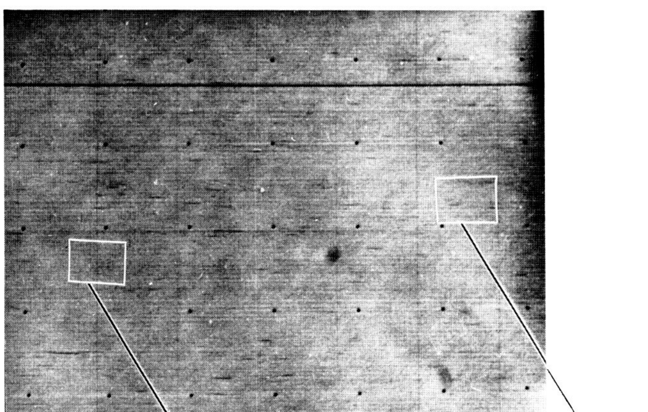


FIGURE 4.—Featureless terrain was photographed by Mariner 7 in 1969.

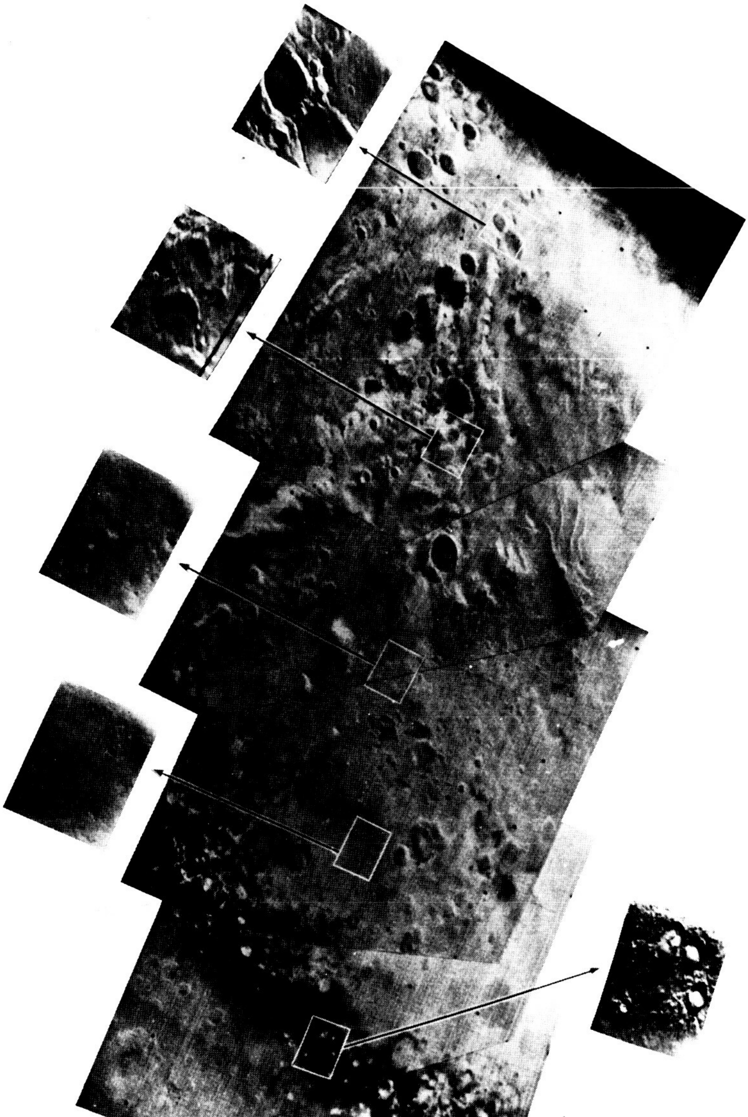


FIGURE 5.—These Mariner 7 photos showed the southern polar cap.

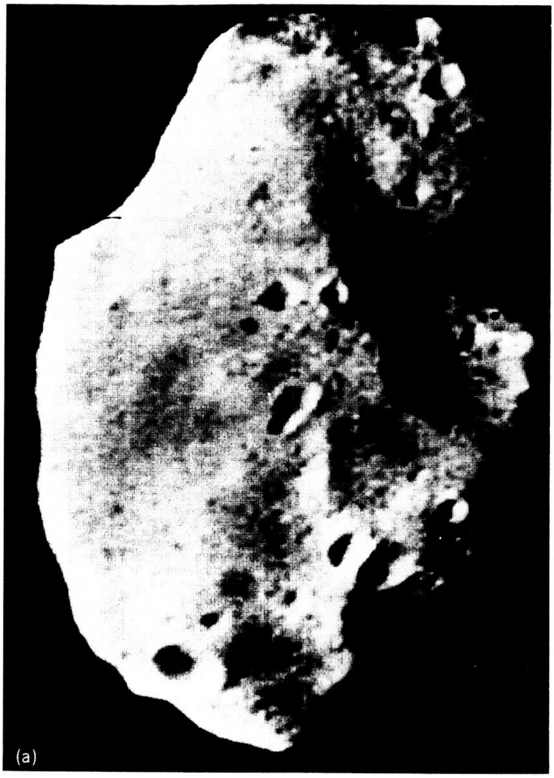


FIGURE 6.—Mariner 9 obtained the first closeup views of the two moons of Mars, Phobos (*a*) and Deimos (*b*).

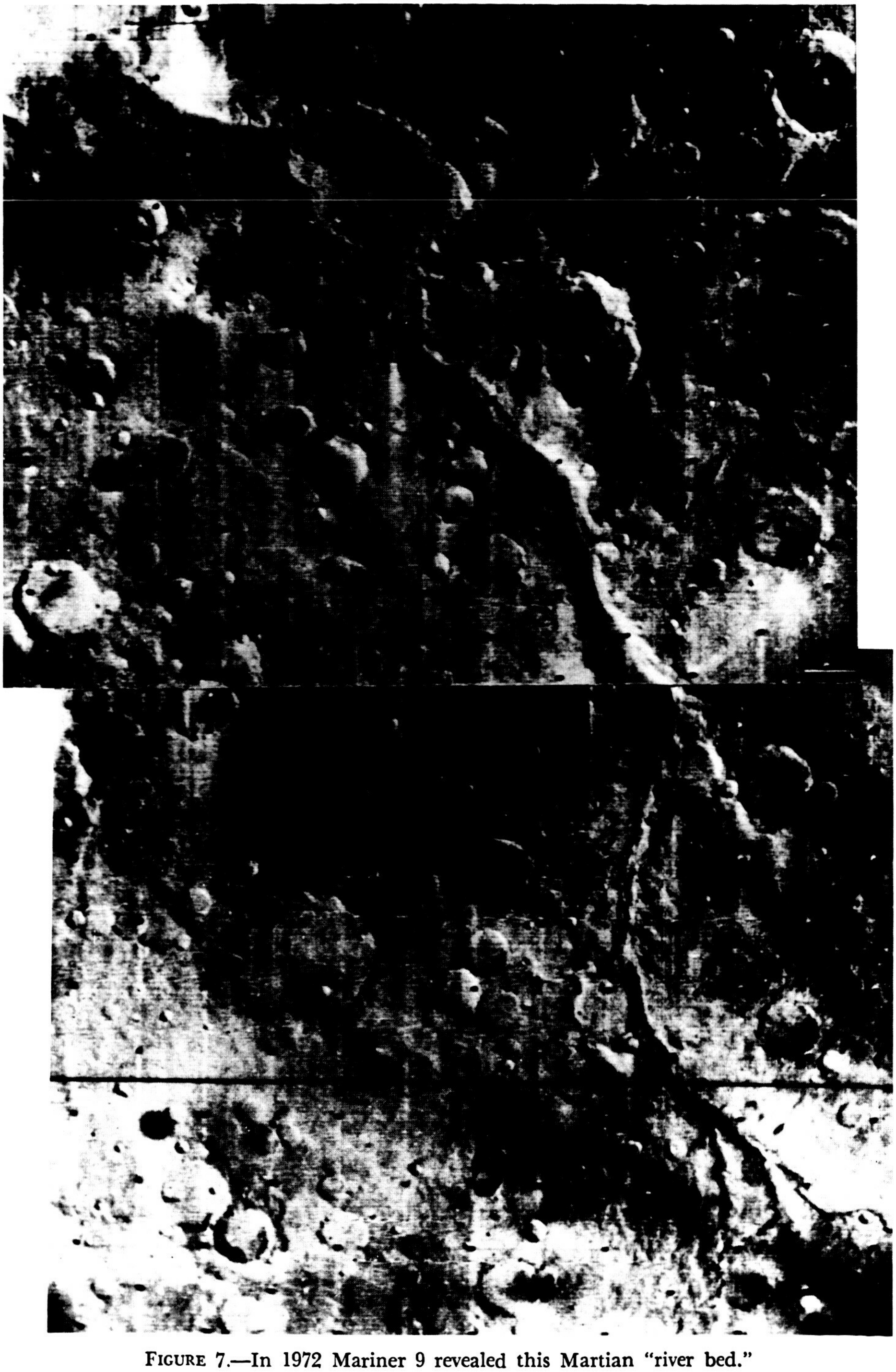


FIGURE 7.—In 1972 Mariner 9 revealed this Martian "river bed."

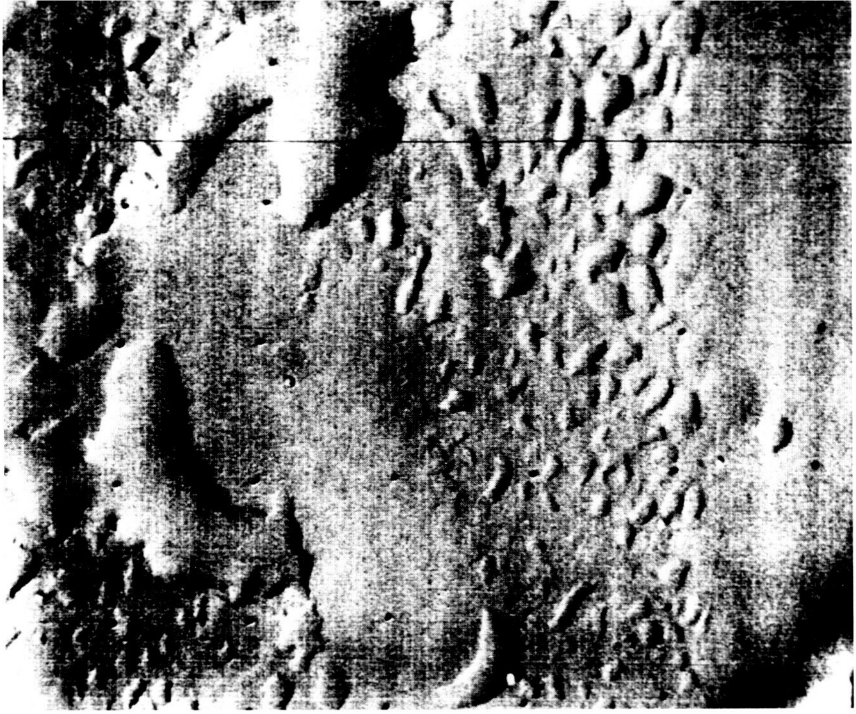


FIGURE 8.—Martian pits and slumps resemble some of the Earth.

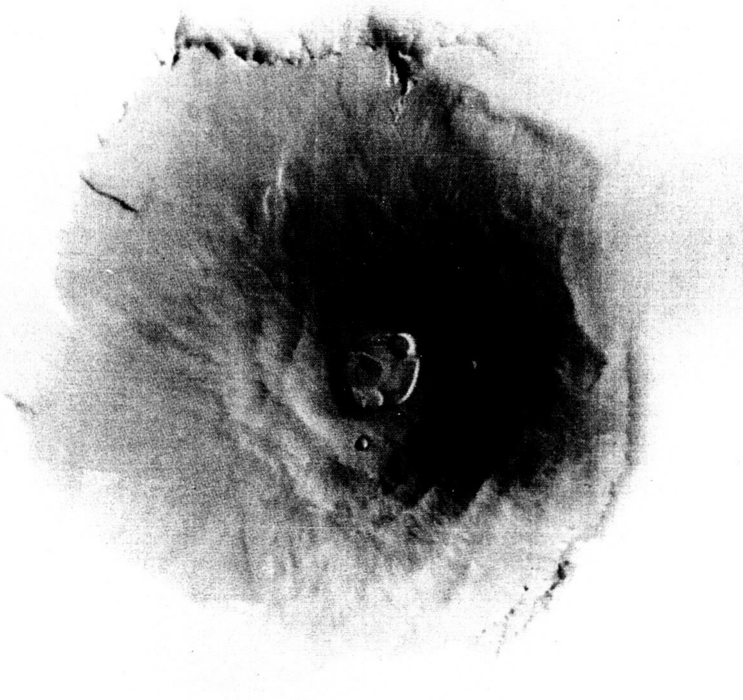


FIGURE 9.—Nix Olympica is a volcano pile twice as wide as Mauna Loa, the largest volcanic pile on Earth.

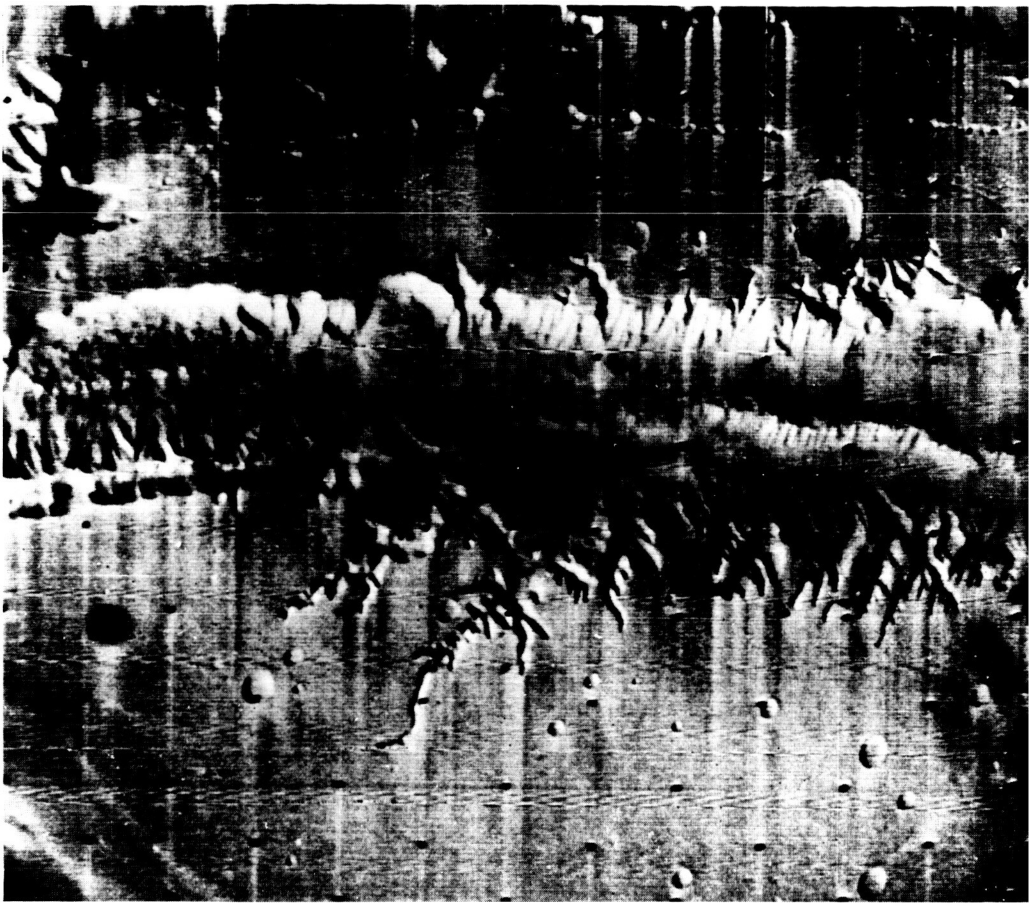


FIGURE 10.—Vast canyon lands were photographed by Mariner 9.

Chapter 3 The Viking Mission

The Scientific Objectives

The goal of the NASA Viking program is to learn more about the planet Mars by direct measurements in its atmosphere and on its surface. Additional scientific data will be acquired from the Orbiter which will circle Mars in a synchronous orbit above the Lander after the latter has descended to the surface. On both the Orbiter and the Lander the primary emphasis will be on biological, chemical, and environmental aspects of Mars which are relevant to the existence of life.

The Viking scientific experiments are divided into four groups: Orbiter, entry, Lander, and radio (table 3). The Lander carries by far the most instruments. It is, in fact, a miniature automated laboratory. The entry experiments involve instruments mounted on a protective shell surrounding the Lander during its high-velocity entry into the Martian atmosphere. The entry experiments will obviously be brief but will give us a unique opportunity to analyze the characteristics of the Martian atmosphere from top to bottom. After the Lander is detached, the Orbiter plays mainly a supporting role, although it may, for selected periods of time, break its radio ties with the Lander and commence independent scientific experiments. The specific instruments associated with the four groups of experiments are listed in table 3. They will be described in more detail in chapter 5.

The Flight Plan

The Viking flight plan consists of five major phases of operations: launch, cruise, orbital, entry, and landed. The operations which must be performed during these phases, in turn, dictate the functional capability of the various parts of the total space vehicle system (fig. 11). This system is described in more detail in chapter 4.

Launch Phase

In the summer of 1975, the launch vehicle will first propel the spacecraft into a 165-kilometer (90-nautical-mile) orbit and, after a short coasting period, inject the spacecraft on a heliocentric trajectory which will intercept Mars nearly a year later (fig. 12).

TABLE 3.—*Viking Scientific Goals and Instruments*

Experiment category	Scientific goals	Investigations (instruments)
Orbiter	Perform reconnaissance to verify or search for landing sites. Monitor landing sites. Obtain data from other areas of the planet. Search for future landing sites.	Visual imaging (2 television cameras). Atmospheric water mapping (infrared spectrometer). Surface temperature mapping (infrared radiometer).
Entry	Determine composition and structural profile of the ionosphere and atmosphere.	Ions and electrons (retarding potential analyzer). Neutral gases (mass spectrometer). Pressure and temperature (pressure, acceleration, and temperature sensors).
Lander	Visually examine the landing site. Search for evidence of life. Search for and study organic and inorganic compounds. Determine atmospheric composition and its variations with time. Determine temporal variations of pressure, temperature, and wind velocity. Determine seismological characteristics. Determine magnetic properties of surface. Determine physical properties of surface.	Visual imaging (2 cameras). Direct biology (3 metabolism and growth detectors). Molecular analysis (gas chromatograph and mass spectrometer) and X-ray spectrometer. Meteorology (pressure, temperature, and wind sensors). Seismology (3-axis seismometer). Magnetic properties (2 magnet arrays and magnifying mirror). Physical properties.
Radio	Conduct scientific investigations using the radio and radar systems.	Radioscience (Orbiter and Lander radio equipment).

Cruise Phase

During the cruise to Mars the Orbiter rocket engines will be used to make midcourse trajectory corrections based on radio-tracking data. Frequent assessments of the spacecraft's "health" will be obtained via the Orbiter's radio. Orbiter science instruments are to be calibrated and used to observe the planet as the spacecraft approaches Mars.

Orbital Phase

Upon insertion of the spacecraft into orbit around Mars with the Orbiter rocket engines, preparations begin for the separation of the Lander capsule. During this time, the Orbiter surveys prospective land-

ing sites chosen with the aid of Mariner 9 science data. After Lander capsule separation, the Orbiter functions as a radio relay and scientific instrument platform in support of the Lander capsule (fig. 13).

Entry Phase

Retrorocket engines on the aeroshell decelerate the Lander capsule out of orbit (fig. 14). It descends to the surface sequentially braked by the aeroshell's aerodynamic drag, by a parachute, and finally by retrorocket engines on the Lander.

Landed Phase

Scientific explorations of the Martian surface can begin when the science instruments are activated and data can be transmitted back to Earth directly via the Lander radio or through a radio relay link with the Orbiter (fig. 15).

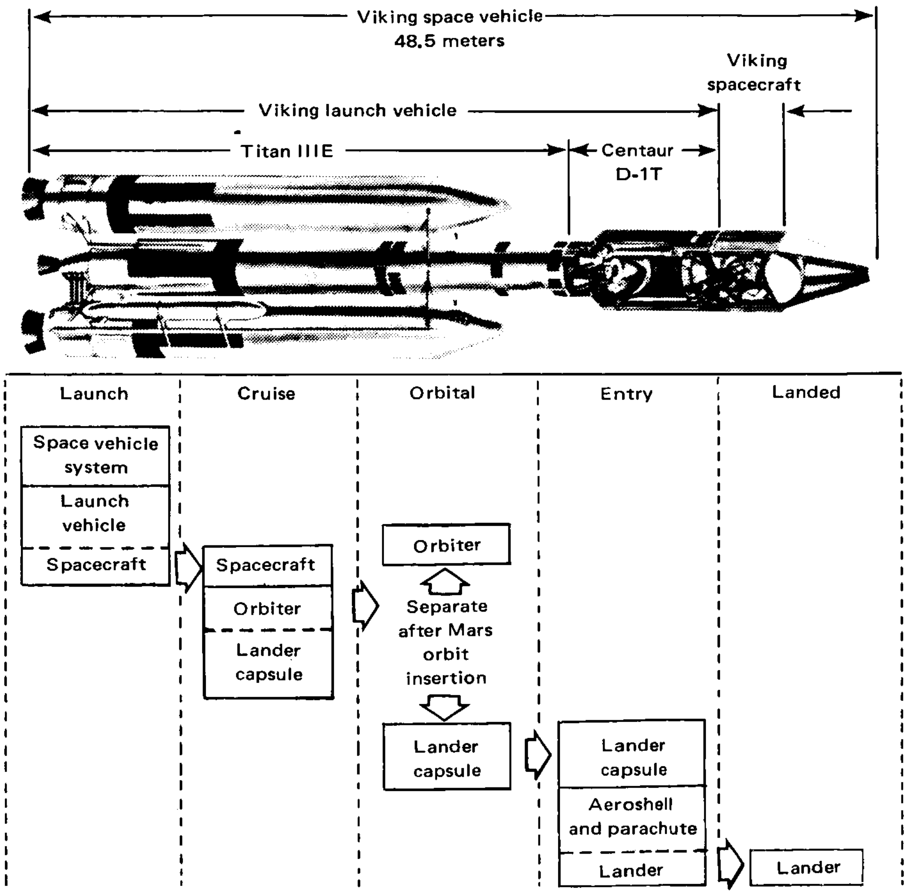


FIGURE 11.—The space vehicle system requires the functional parts indicated here for the mission's five phases.

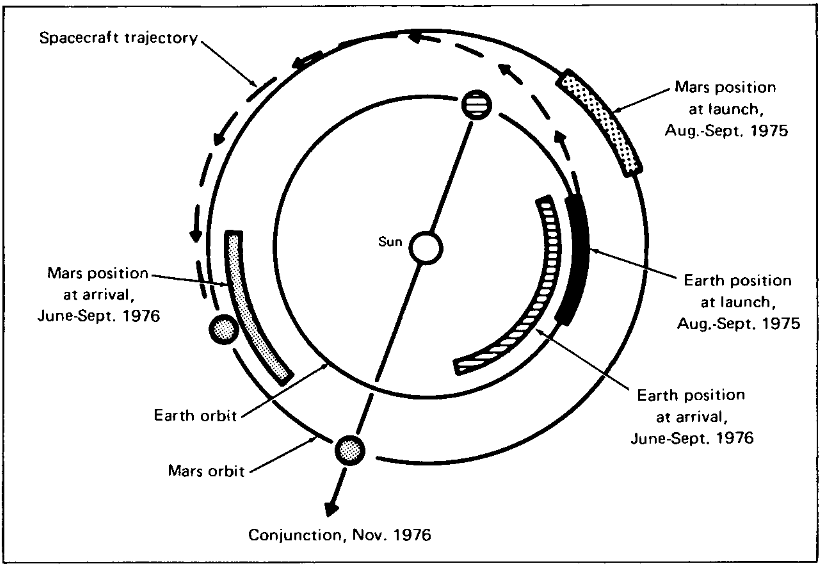


FIGURE 12.—Relative positions of Earth and Mars.

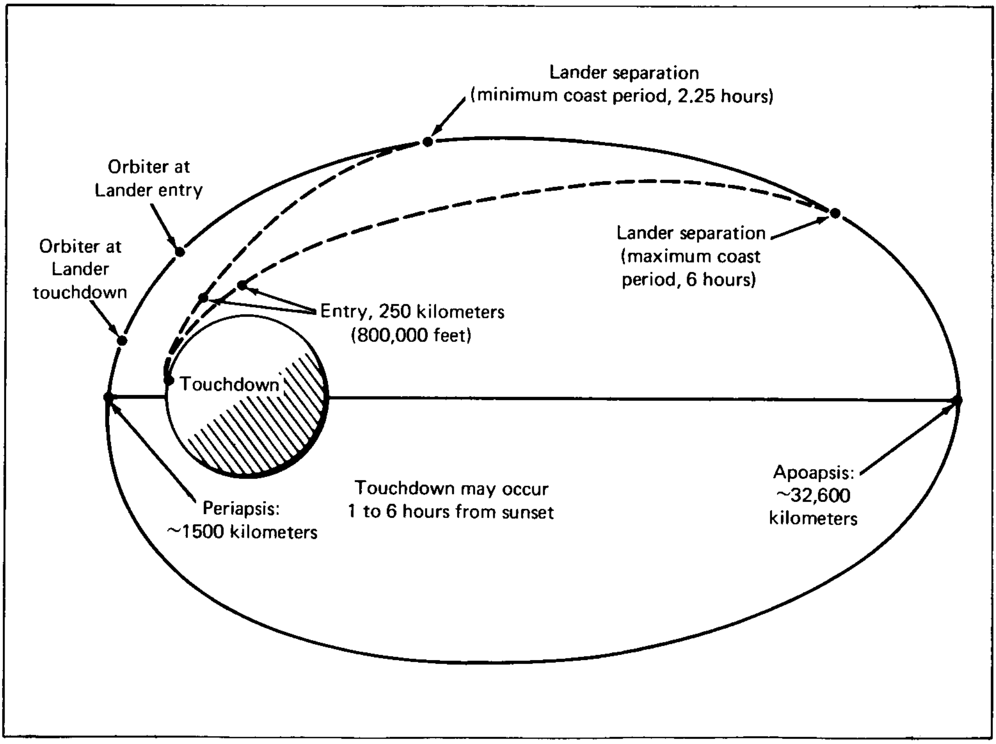


FIGURE 13.—The orbital phases of the flight.

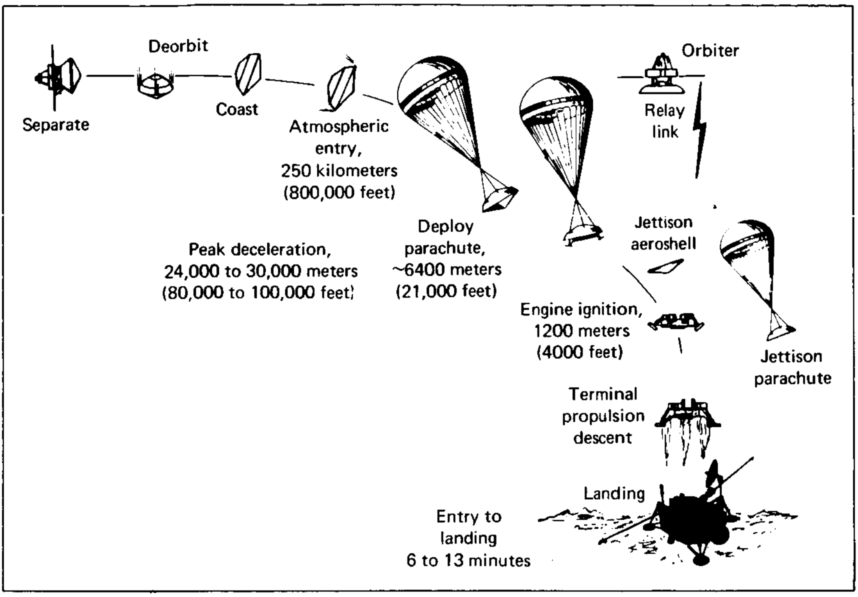


FIGURE 14.—How the Lander will reach the surface.

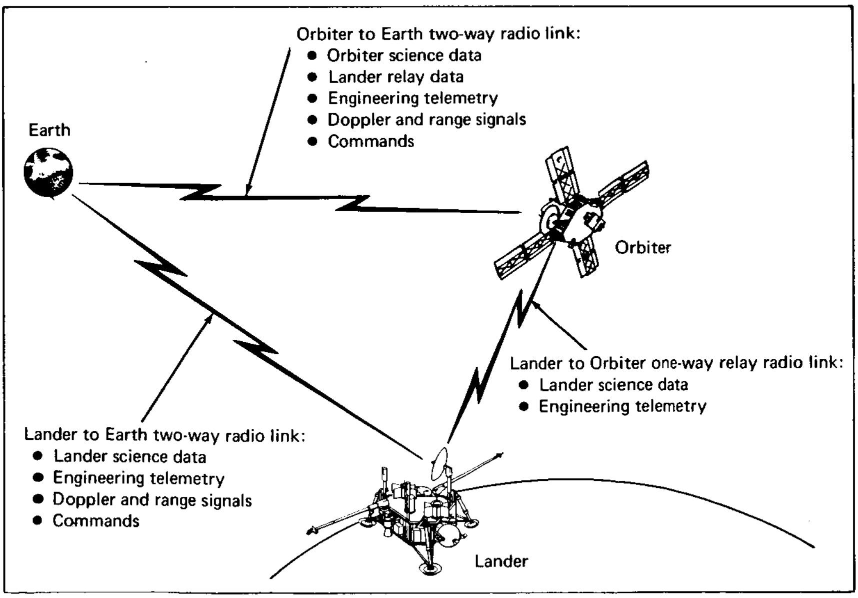


FIGURE 15.—Two-way radio links will transmit information between the Earth and both the Orbiter and the Lander.

Chapter 4
The Spacecraft and Launch Vehicle

The launch vehicle and spacecraft are the most novel parts of Viking. In contrast, the tracking stations, computers, and other equipment left behind on Earth get little fanfare. Yet a complete understanding of Viking demands knowledge of all pieces of interacting hardware. Viking actually comprises the six "systems" portrayed in figure 16, three of which never leave the ground. In this section, each of these systems will be described in more detail. None is independent of any other system; parts have to fit together mechanically, common radiofrequencies must be used, and a host of other "interfaces" have to be mutually compatible.

The Orbiter

During the long flight to Mars, the Orbiter is the dominant part of the spacecraft. The Lander is maintained in a quiescent state during these 10 to 12 months. At this time the Orbiter provides spacecraft stabilization and maintains the only telemetry and command links with the Deep Space Network (DSN) back on Earth. The dormant Lander also receives life-sustaining electrical power from the Orbiter. Periodically, the Orbiter relays "housekeeping" data from the Lander to DSN antennas so that engineers can assess the Lander's mechanical well-being.

The Orbiter is much more than a nursemaid to the Lander. As the spacecraft approaches Mars, it is the Orbiter's engine which slows it down to make gravitational capture possible. After a satisfactory orbit has been attained, the Orbiter scans several preselected landing sites with its television cameras and other instruments to provide data to the flight operations team for a final choice. With this decision, the Lander is commanded to operational status and checked out for landing on the planet.

During the separation and entry of the Lander capsule, the Orbiter serves as the vital communication relay link with Earth. Even after a successful landing, the Orbiter communication relay link is the primary method of transmitting Lander data back to Earth. The Orbiter-Lander cooperation continues through the remainder of the mission, with the Orbiter storing data received from the Lander for retransmission to Earth when the planet's rotation carries the Lander to the side of Mars away from Earth. While in orbit administering to the Lander, the Or-

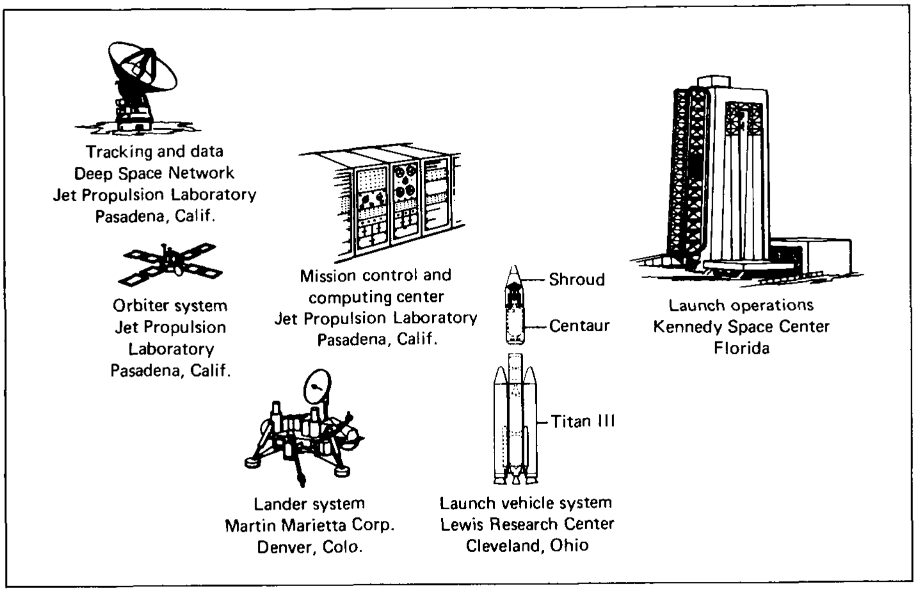


FIGURE 16.—Viking systems.

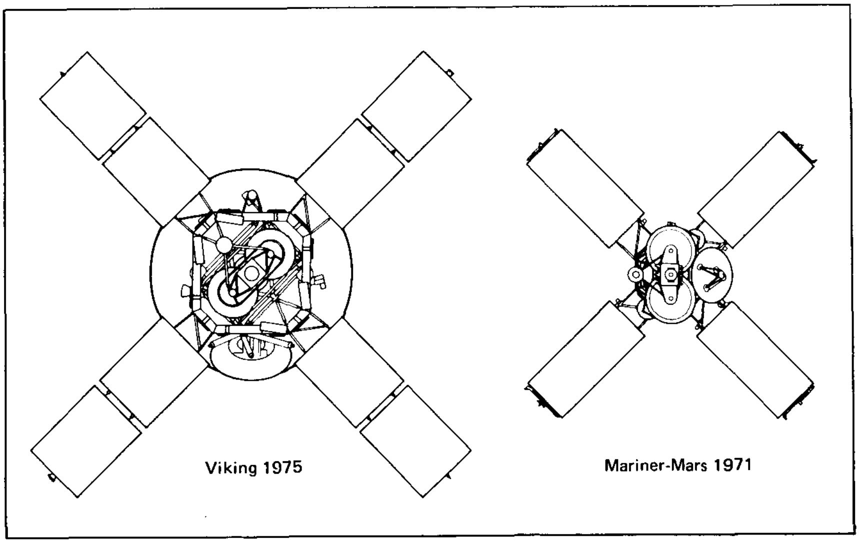


FIGURE 17.—Comparison of Viking and Mariner spacecraft.

biter scientific instruments also scan Mars for data for it to telemeter back to Earth.

The design of the Viking Orbiter is derived from the Mariner series of spacecraft. Originally, it had been hoped that a slightly scaled-up Mariner 9 spacecraft would suffice. The Orbiter resembles a Mariner

(fig. 17), for the arrangement of components is generally similar and Mariner design philosophy was employed throughout. There are differences, however, because the Viking Orbiter has tasks not on Mariner 9's list. The whole Orbiter structure was influenced by the much larger propellant tanks required by Viking. Not only does the Orbiter have to decelerate so that it can be captured by Mars but it also must decelerate the attached Lander capsule. Consequently, the propellant tanks are three times the size of those of Mariner 9—1600 kilograms (3137 pounds) of propellant in two tanks, each 140 centimeters (55.1 inches) long and 91 centimeters (35.8 inches) in diameter. These tanks can be seen in figure 18 just atop the polygonal spacecraft structure. There is a 64-centimeter (25.2-inch) spherical propellant-pressurizing tank nested within the structure. In addition to the extra "muscle" needed by the Viking Orbiter, designers provided more brainpower than Mariner 9 had. The Orbiter, having to perform more complex functions than Mariner 9, possesses two 4096-word, general-purpose computers operating in parallel or tandem rather than the small, special-purpose computer of its predecessor. The faster picture-taking rate of the Orbiter (needed for landing-site verification) required a 2.112 megabits per second tape recorder capable of storing 55 television frames, or over half a billion bits.

Like the Mariners, the shape of the Viking Orbiter structure is a rather flat octagonal prism. This structure has unequal sides 216 by 252 centimeters (85 by 99.2 inches) along the diagonals. Other Orbiter components are appendages attached to the basic octagonal structure.

Thermal control is critical for electronic and many other subsystem components. Windowblindlike louvers around the periphery of the octagon open and close automatically to permit individual cooling of 16 equipment bays built into it (fig. 19). The propellant tanks are shielded from the direct sunlight by a multilayer blanket of insulation. The propulsion module temperature is regulated by four solar energy reflectors mounted on the rim of the octagon to direct sunlight to the sides of the thermal blankets (fig. 18).

The X-shaped silhouette created by the four solar panels is a Mariner trademark. Each panel is hinged at its base to an outrigger structure and hinged again halfway out. Viking solar panels thus fold double for stowage inside the fairing of the launch vehicle instead of once like other Mariner designs. Together, the solar panels present just over 15 square meters (23,250 square inches) of solar cells to the Sun. At the distance of Mars, the cells generate 620 watts of electrical power. When this amount of power is insufficient to handle peak loads, or when the Orbiter turns away from the Sun—as it must do for the braking maneuver at Mars—supplementary power is provided by two 30-ampere-hour nickel-cadmium storage batteries.

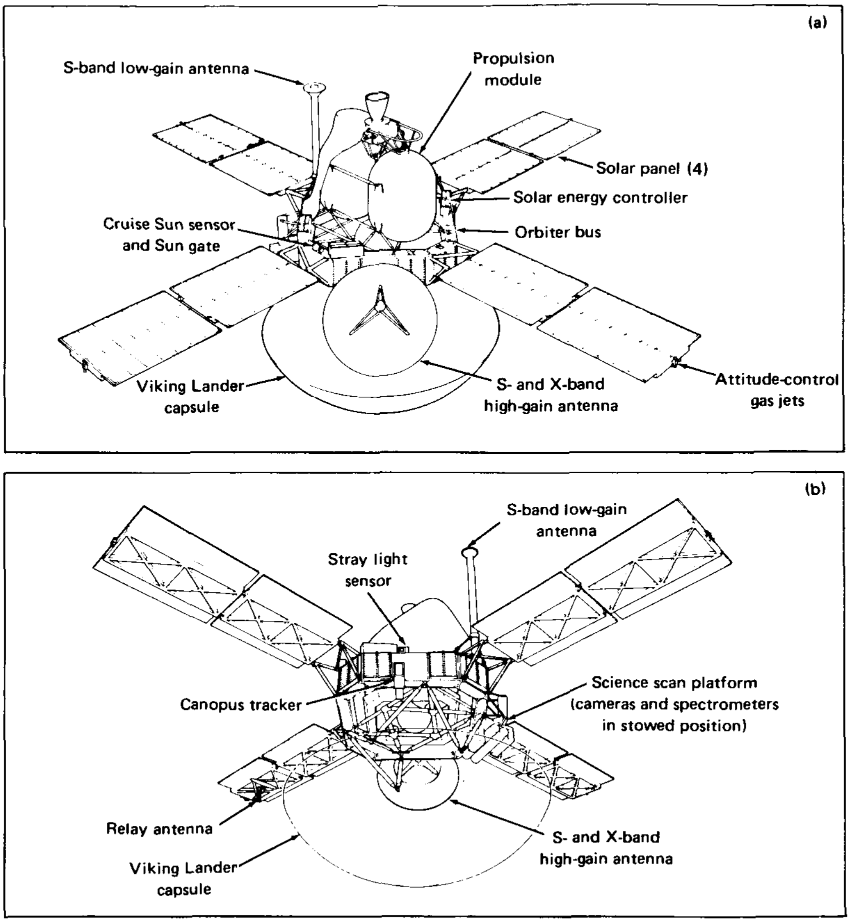


FIGURE 18.—Orbiter (with Lander capsule attached). (*a*) Top view. (*b*) Bottom view.

Information is the lifeblood of any unmanned space mission. The object is to radio as much scientific information as possible from Orbiter and Lander to Earth. The Orbiter's telecommunication subsystem is depicted in figure 20. The mainstay of this subsystem is a parabolic high-gain antenna 147 centimeters (57.9 inches) in diameter, motor-driven about two axes. The two degrees of freedom mean that the narrow cone of radio energy emitted by the antenna can be directed right at Earth. Communication at high bit rates at the distance of Mars would be impossible unless the Orbiter's transmitter power were concentrated in this way.

Communication between Orbiter and the DSN must be two-way because terrestrial controllers have to send commands to the spacecraft to carry out certain functions, such as to turn on the cameras or to separate the Lander. In fact, spacecraft designers try to insure that it is *always* possible to send commands to the spacecraft and to receive lim-

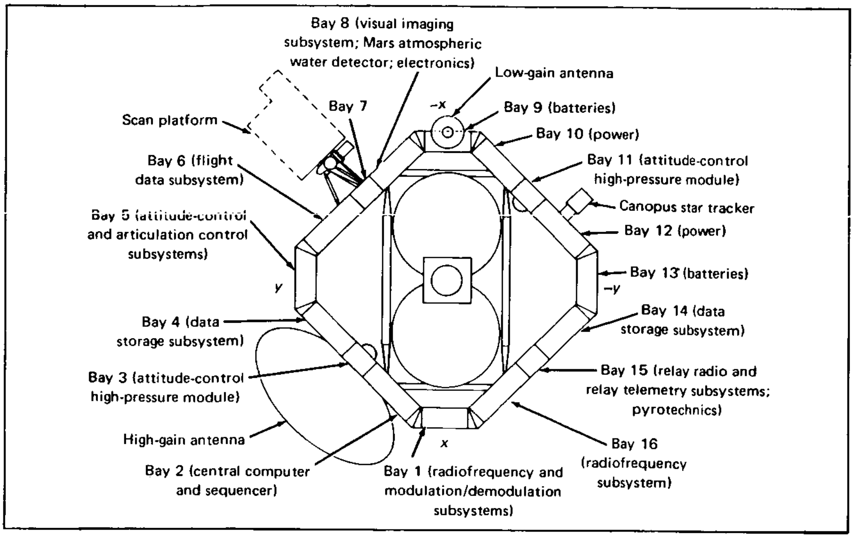


FIGURE 19.—Orbiter electronic bays.

ited telemetry regardless of whether its high-gain antenna is pointing at Earth. (It very likely will not be during some of the Orbiter's maneuvers.) Therefore, on the sunlit side of the spacecraft (fig. 18) is a rodlike low-gain antenna with a small cone at its tip. Not as directionally sensitive, it allows limited two-way communications with Earth over greater than hemispherical coverage.

The last of the Orbiter's complement of antennas is mounted on the end of one of the solar panels. This antenna is solely for communication traffic between Orbiter and Lander on the surface.

The Orbiter's role as a communication relay can be seen in figure 21, which depicts the direct communication link possible between the Lander and DSN, and the potential links that may be established between Orbiter A and Lander B and Orbiter B and Lander A.

The Orbiter's transmitter power is about 20 watts. Most terrestrial commercial radio stations broadcast hundreds of times this amount of power. How can so weak a signal be detected after traveling hundreds of millions of miles? The ultrasensitive 64-meter (210-foot) diameter antennas of the DSN help make interplanetary communication possible. They have already recorded the 10-watt signals of the interplanetary Pioneer spacecraft at well over 200 million miles. At these tremendous distances the rate of information flow is very small. Most of the time, the so-called "bit rate" will be only 8⅓ bits per second from the Viking Orbiter, which amounts to about one scientific or housekeeping measurement per second. However, when the Orbiter's high-gain antenna is directed right at a 64-meter DSN antenna, it is planned to send data at 4000 bits per second.

Scientific data telemetered to Earth will also come from the Orbiter's own scientific experiments. These instruments will scan the surface of Mars looking for warm, wet areas and checking out the preselected landing spots prior to the descent of the Lander. The cameras and spectrometers are mounted on a scan platform similar to that used on Mariner 9.

The Orbiter-Lander combination must also be pointed precisely, while the Orbiter propulsion unit injects the spacecraft into Martian orbit. How does the spacecraft find its actual orientation and then change it to the desired orientation? The two celestial references used are the Sun and the star Canopus. Viking's photoelectric sensors lock onto these known objects, enabling the spacecraft to maintain a fixed attitude in space. When either the Sun or Canopus cannot be seen because of occultation by Mars, an inertial reference unit provides the guidance information.

Attitude-control jets are located at the tips of each of the four solar panels, giving them lever arms (fig. 18) of 483 centimeters (190 inches). Nitrogen gas for the jets is stored in two 30-centimeter (12-inch) bottles. The Orbiter's attitude-control subsystem automatically commands the opening and closing of the jet valves to release bursts of cold nitrogen gas which are used to nudge the spacecraft into the desired orientation.

The Orbiter as a whole weighs 2324 kilograms (5125 pounds) at launch, compared with Mariner 9 which weighed in at 978 kilograms

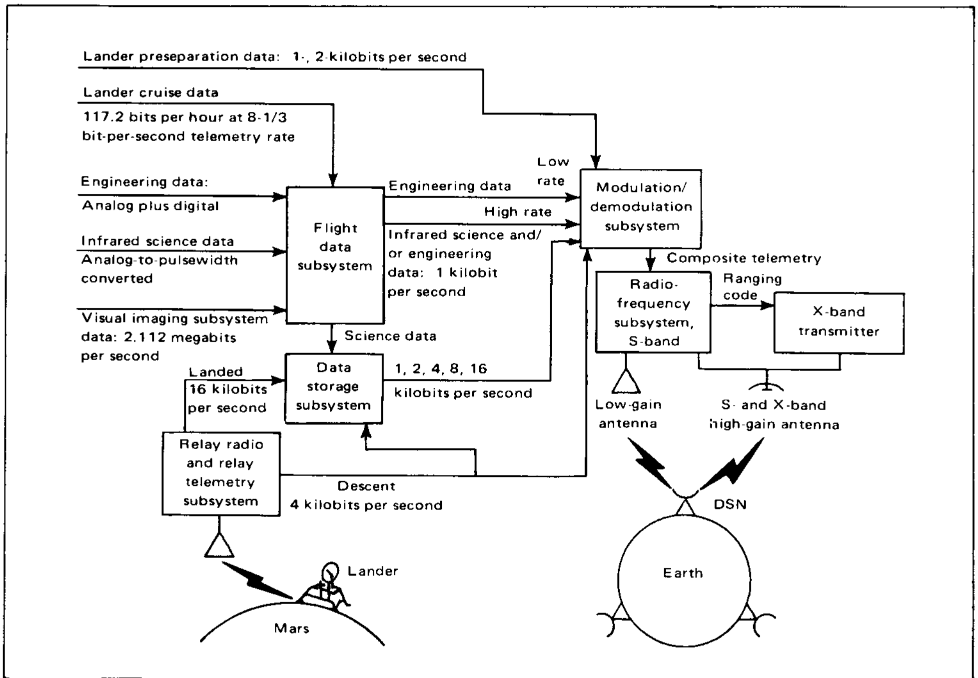


FIGURE 20.—Orbiter telecommunication subsystem.

(2150 pounds). Much of the additional weight is propellant, reflecting the bigger braking task at Mars. But the Viking Orbiter also has to provide for storage of data from the Lander, extra communications tasks, and the long job of caring for the inactive Lander during flight

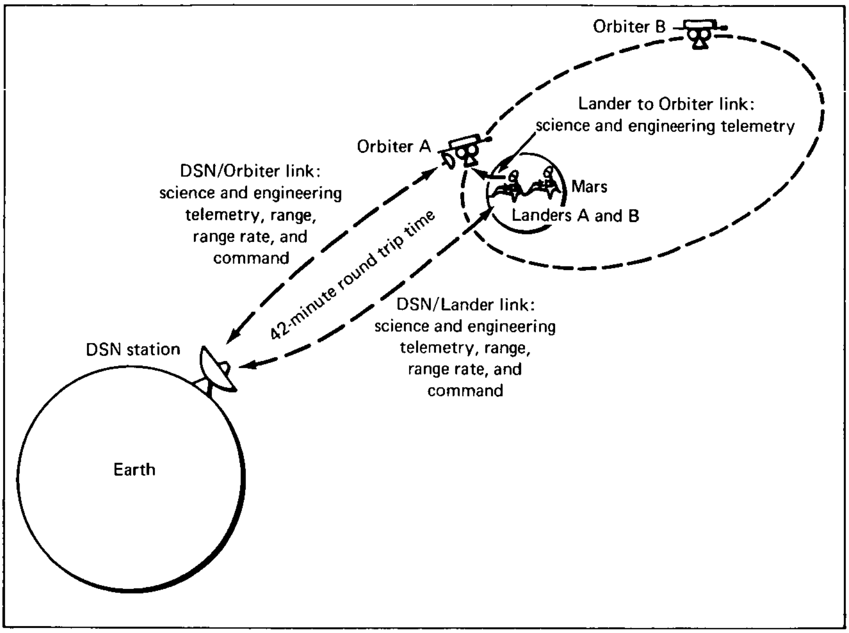


FIGURE 21.—Communication links.

from Earth. All these functions require more equipment, more power, and, naturally, more weight.

The Lander

The focus of activity changes from the Orbiter to the Lander as retrorockets slow the Lander down and it begins to fall toward the surface of Mars.

The first major task of the recently awakened Lander is its safe descent through the thin Martian atmosphere to the selected landing site. The Martian atmosphere, though only a hundredth as dense as Earth's, requires that the Lander be thermally protected during the initial entry phase when it is still traveling sixteen thousand kilometers per hour. A second complicating factor is the necessity for "canning" or biologically isolating the Lander from the time it is sterilized on Earth until it is outside Earth's biosphere. Scientists want to make sure that no terrestrial life forms are carried along to confound their search for native life forms on Mars or to contaminate the planet.

The Lander is actually in a double "can" until separation of the bio-

shield cap outside Earth's biosphere. Thus sealed and pressurized, the Lander capsule is protected against biological invasion from the unsterilized Orbiter (fig. 22). The lens-shaped bioshield is 365.7 centimeters (144 inches) in diameter and 193.8 centimeters (76.3 inches) from top to bottom. It is constructed from coated woven Fiberglas 0.0013 centimeter (0.005 inch) thick. The material is intentionally thin to reduce weight. The bioshield is pressurized and hermetically sealed to prevent biological invasions during the launch. The aeroshell and base cover nest inside the bioshield, as shown in figure 22. The aeroshell's basic structure is 0.008-centimeter (0.034-inch) aluminum alloy formed into a 140° cone stiffened with concentric rings. It takes the full brunt of aerodynamic forces during entry. Bonded to its outside is a corklike material which protects the contained Lander from the searing temperatures (1500° C (2700° F)) created by aerodynamic heating. Attached to the aeroshell are a base cover and parachute system. The parachute slows the Lander descent further after atmospheric drag has reduced the Lander's velocity to about 375 meters per second (1230 feet per second) at 6400-meter (21,000-foot) altitude. At about 1200 meters (4000 feet) the parachute is jettisoned and the Lander descends slowly to the surface using three terminal descent engines to retard its fall.

The well-protected Lander rests inside its shells like a butterfly in the chrysalis stage. Its appendages are all retracted. When the aeroshell is jettisoned, the Lander legs are extended, and after landing the other appendages (high-gain antenna, meteorology boom, and sample arm) are extended.

During the long flight from Earth, an umbilical connection through the base cover provides power to the Lander. Housekeeping data also flow through this connection. Once small explosive charges break the connections, the Lander plus aeroshell are separated from the Orbiter.

The aeroshell is not merely a passive aerodynamic shield. The two spheres shown in figure 22 contain hydrazine monopropellant to feed four small rocket engines located around the edge of the aeroshell. These rockets slow down the Lander and allow it to be pulled toward Mars by gravity. They also provide pitch-and-yaw control to orient the aeroshell in the proper attitude for entering the atmosphere. Aeroshell roll control is provided by eight similar rockets colocated with the pitch-and-yaw engines. As the Lander capsule descends (fig. 14), a solid-state pulse radar transmitting at 1000 megahertz performs as an altimeter.

At about 6400 meters (21,000 feet) above the surface, the radar signals a mortar housed in the base cover to fire and deploy a lightweight polyester parachute. Its diameter is 16.2 meters (53 feet), and extralong suspension lines separate it from the Lander by almost 30 meters (100 feet).

At about 1200 meters (4000 feet) the parachute is also jettisoned and the terminal descent engines are fired. A continuous-wave Doppler

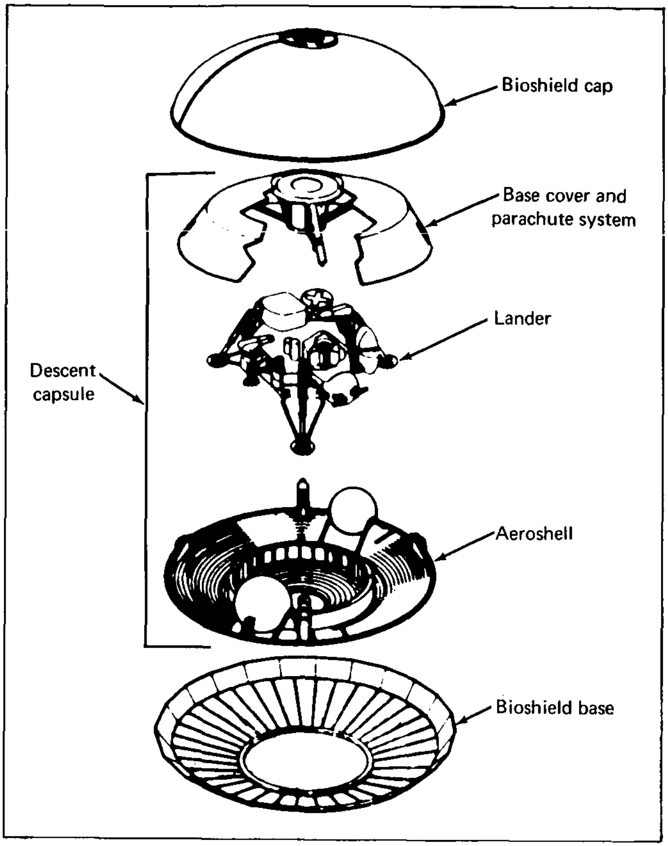


FIGURE 22.—Exploded view of encapsulated Lander capsule.

radar, which directs four canted beams toward the Martian surface and operates at 13,000 megahertz, measures the Lander's horizontal velocities to within 1 meter per second. Another radar measures its altitude. These radars provide altitude and velocity data which control the firing of three retrorockets to finally ease the Lander down to the surface. (The parachute alone cannot do the job in the rarefied Martian atmosphere.) Like the aeroshell's much smaller rockets, those on the bottom of the Lander utilize hydrazine monopropellant (fig. 23). Spaced equidistant around the Lander's frame, they control the pitch-and-yaw attitude of the Lander as well as braking its descent. Roll control is provided by four other engines located on the hydrazine tanks.

The difficult problem of "site alteration" was solved by an unusual array of 18 nozzles on each of the Lander engines. When a spacecraft eases down to a surface with its descent engines firing, the ground underneath may be scoured over a wide area by the rocket blast. Furthermore, the soil is heated—perhaps killing any indigenous life forms—and extraneous chemicals are added to the soil by the burning fuel. Ordi-

nary hydrazine, for example, can introduce hydrogen cyanide, water, and ammonia. Originally, Viking engineers contemplated turning off the descent engines about 2.5 meters (10 feet) above the surface and letting the Lander fall the rest of the way. Then it was found that ultrapure hydrazine would not contaminate the surface and that an array of small nozzles would spread the exhaust gases out into a wide, gentle fan that would not unduly disturb the chemical and biological experiments to follow. The Lander's descent engines will be turned off by switches in the three strutlike legs projecting from its body. Inside each main landing strut is crushable aluminum honeycomb material which cushions the final impact.

The deorbit-descent-landing sequence presents a complex control problem. To make matters more difficult, next to nothing can be done from Earth because, even at the velocity of light, a command will take on the order of 20 minutes to reach the Lander. It would take an equally long time for the Lander to signal terrestrial controllers that it is in

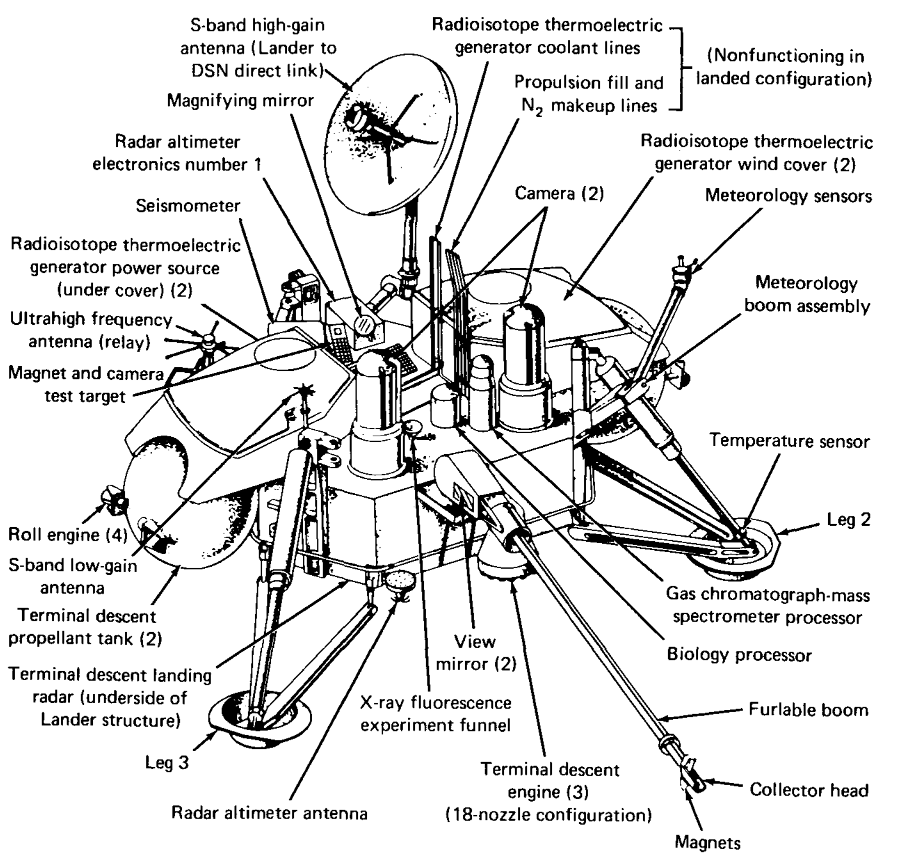


FIGURE 23.—Lander.

trouble. The only way to control the deorbit-descent-landing sequence is by automation. The Lander is on its own until touchdown. In fact, it has in its computer memory stored instructions which could control the first 22 days of experimentation without contact from Earth. The Lander is, by today's standards, a fairly intelligent robot.

Once on the surface with all its appendages extended, the Lander somewhat resembles the unmanned Surveyor spacecraft NASA landed on the Moon prior to the manned Apollo flights. The Viking Lander owes a considerable debt to Surveyor technology, but its designers have had to wrestle with three new problems: The technology of sterilization, the requirement for a much higher degree of autonomy because of signal time delay from Earth, and the yearlong dormant state.

NASA has always met the internationally established planetary quarantine requirement for payloads headed for Mars and other planets. The internationally accepted criterion for planetary quarantine is that there be only a 1-in-1000 chance (0.001 probability) of contamination by terrestrial organisms during the 50-year period beginning January 1, 1969. Because there may be many spacecraft exploring Mars within that period, the sterilization specifications for each Viking launch are more stringent: less than 1 chance in 10,000 (0.0001 probability). To achieve this low probability, the entire Viking Lander capsule sealed in its bioshield is baked in an oven for several days. The coldest part of the Lander must register about 112° C for sufficient time to insure that enough of the micro-organisms have been killed to meet these very small probabilities of contaminating Mars.

The heat of sterilization not only kills micro-organisms but also risks injury to many Lander components. Even though many pieces of Lander hardware were borrowed from space programs where they had proven themselves, the rigors of heat sterilization caused some failures during the Viking test program that necessitated a redesign of these components or selection of alternate components impervious to the heat levels.

The "brain" behind the critical descent maneuvers is called the guidance control and sequencing computer (GCSC). The sequencing part of its name refers to automation of the actions that follow a successful landing. The instructions (22 days' worth) are stored in the GCSC. They may be updated and modified by Earth once communication has been established. Even under the best conditions, however, the Lander will be out of sight about 12 hours each day as the rotation of Mars carries it around the far side of Mars where terrestrial antennas cannot communicate with it.

The GCSC was one of the greatest technical challenges of the Viking Lander. It consists of two general-purpose computers with plated-wire memories, each having 18,000 words of storage. One computer will be operational while the other is in reserve. The operating computer sends a periodic "I'm OK" signal back to Earth. If it is not OK, the Lander

automatically goes into standby mode and waits for the reserve computer to take over and begin to reactivate the Lander.

With all its appendages deployed (fig. 23), the Lander structure is hard to discern. Basically, it is a hexagonal box 1.494 meters (58.8 inches) wide and 0.457 meter (18 inches) thick. The major structural materials of the box are aluminum and titanium alloys. Landing legs, antennas, and instrument sensors project from it.

Once safely on the surface, two vital functions of the Lander are the supply of electrical power and the maintenance of communication with the Earth—directly or by Orbiter relay. Let us look at the power problem first.

Sunlight is one-half as strong at the orbit of Mars as in Earth's orbit, and it is nonexistent during the frigid Martian night. The radioisotope thermoelectric generator (RTG) was the logical choice for the Viking Lander because it is a long-lived source of both electricity and heat. The two Viking RTG's (fig. 24) convert the heat from decaying plutonium-238 into 70 watts of electric power with thermoelectric elements. The "waste" or unconverted heat is conveyed via a thermal switch to a

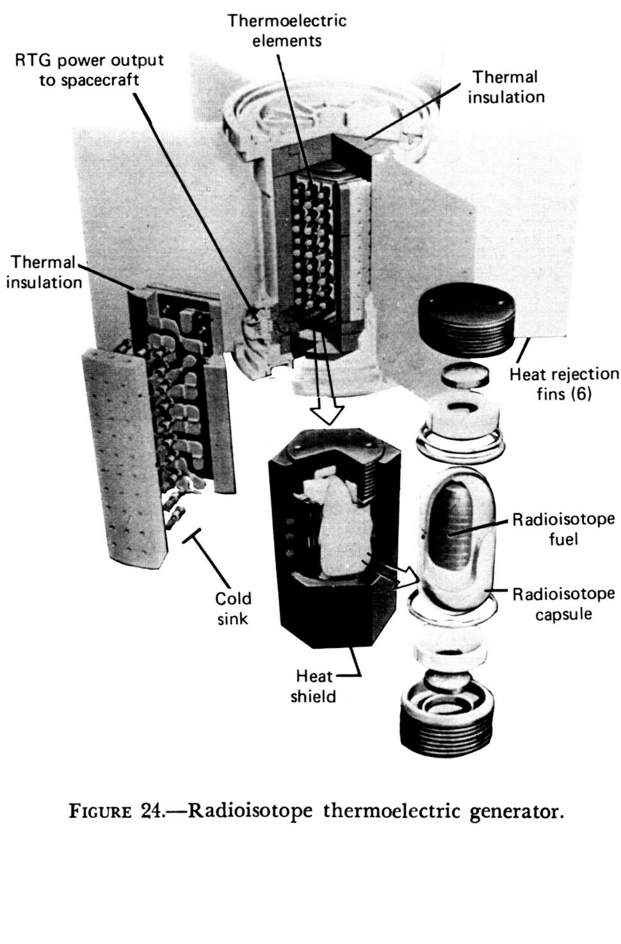
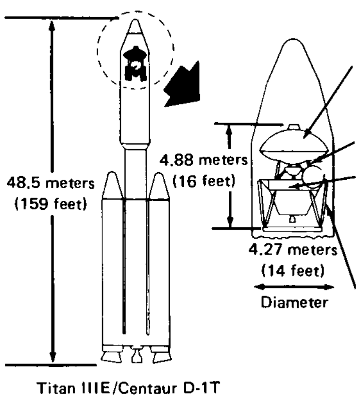


FIGURE 24.—Radioisotope thermoelectric generator.

temperature-controlled instrument compartment. A windscreen (shown covering the RTG's in fig. 23) insures that waste heat from the RTG's will be available for the instruments and not dissipated uselessly to the environment. Heat on Mars is a valuable commodity for the Lander because at night the atmospheric temperature may drop as low as −120° C (−184° F).

Data from the Lander's scientific instruments and its internal housekeeping measurements can follow either of two routes back to Earth. The highest data rate is via an Orbiter. Data stored on the Lander tape recorder can be transmitted at high speed (16,000 bits per second) along an ultrahigh frequency link to an Orbiter when it passes overhead. The Orbiter records this information on its tape recorder and retransmits it over its S-band radio link to terrestrial DSN antennas.

The second electronic pathway, completely redundant to the relay link, is the Lander's direct S-band link with Earth via its computer-steered high-gain antenna located on top of the Lander. With this 0.762-meter (30-inch) parabolic dish, the Lander can transmit directly to a 64-meter (210-foot) DSN antenna at up to 500 bits per second. If the Viking Orbiters should fail, all Lander data would take this alternate route.



	Kilograms	Pounds
Lander capsule	1118	2464
(Usable Lander propellant)	(139)	(307)
Lander capsule adaptor	16	35
Orbiter	2325	5125
(Usable Orbiter propellant)	(1406)	(3097)
Spacecraft	3458	7624
Spacecraft adaptor	61	135
Total Viking spacecraft system	3519	7759

FIGURE 25.—Viking spacecraft allocated weights.

Four Tons to Mars

The weight of the Viking Orbiter and Lander plus propellants and adaptors is about 3600 kilograms (4 tons) (fig. 25). Mariner 9 weighed only 978 kilograms (2150 pounds), less than one-third the Viking payload. The Atlas-Centaur launch vehicle used for propelling Mariner 9 to Mars is much too small for Viking. On the other hand, the NASA Saturn V launch vehicle built for the Apollo program is too big by a

factor of 2. The most economical approach to furnishing the requirements of Viking is to use the Titan III rocket with a Centaur upper stage, a combination that can place about 3600 kilograms (8000 pounds) in the vicinity of Mars.

The Titan III/Centaur combination (fig. 26) is a relatively new launch vehicle, although each part has been used on other missions. Standing 48.5 meters (159 feet) high on the launch pad, the Titan III/Centaur does not have the streamlined, monolithic look of the

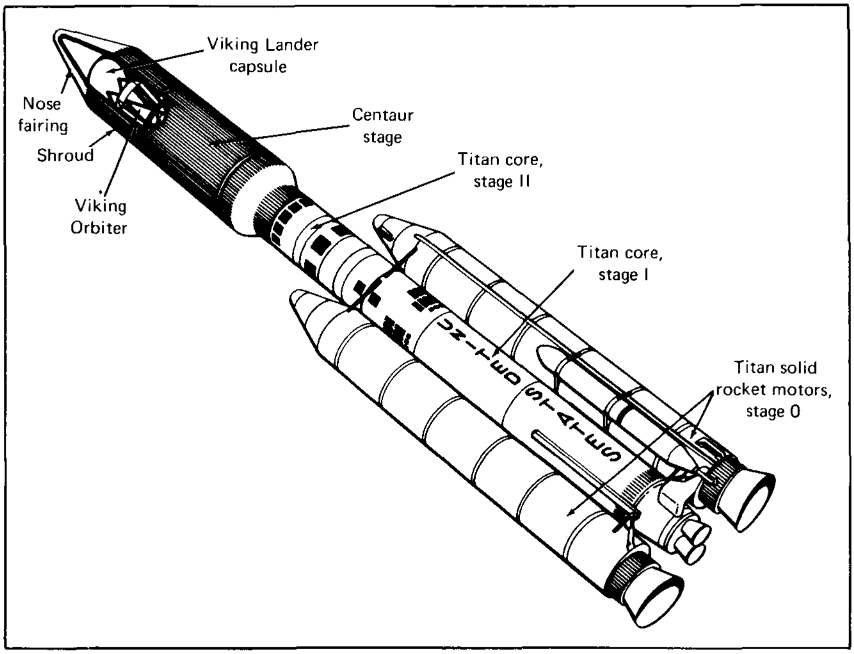


FIGURE 26.—Viking space vehicle configuration.

Saturn V. The Titan III is assembled by taking a two-stage Titan II rocket for a core and strapping on two large solid rockets for added thrust. The solid rockets are each 3.05 meters (10 feet) in diameter and 25.9 meters (85 feet) long. Their fuel is powdered aluminum in a rubber matrix. This is burned with ammonium perchlorate to generate about 4,893,230 newtons (1,100,000 pounds) of thrust per rocket at liftoff. The solid rockets (called the zeroth stage) burn out after about 2 minutes and are jettisoned over the Atlantic. The Titan core, consisting of a two-stage liquid rocket 3.05 meters (10 feet) in diameter, does not ignite until just before the solids burn out. Both liquid stages burn a blend of hydrazine and unsymmetrical dimethylhydrazine fuel with nitrogen tetroxide oxidizer. The first stage burns for about 2½ minutes; the second stage for about 3½ minutes. Then the Centaur upper stage takes over.

The Centaur is one of NASA's high-performance upper stages, developed primarily for lunar and interplanetary work. Its two engines generate a total of about 133,452 newtons (30,000 pounds) of thrust by burning hydrogen with oxygen. A feature of Centaur is that its engines can be restarted in space, which is essential in the Viking mission. After the Titan second stage is jettisoned, the Centaur first propels the Viking into a 165-kilometer (90-nautical-mile-high) parking orbit around Earth, where it waits between 6 and 30 minutes for the proper moment to depart for Mars. When this arrives, the Centaur is restarted and injects Viking into a heliocentric trajectory to intercept Mars nearly a year later. Centaur's final act is to separate itself from Viking, and, by expelling its residual propellants, deflect itself away from the Viking trajectory to minimize the chance that it will impact on Mars.

The Terrestrial Part of Viking

As the Titan III/Centaur lifts Viking off the launchpad, all terrestrial ties are broken except those using electromagnetic waves. By terrestrial standards, Viking's radio voice is weak (20 watts). Once it leaves its parking orbit for Mars it would be invisible and effectively lost if its radio transmissions could not be heard. To pick up the weak signals the Earth-bound part of Viking must be correspondingly large. And if Viking is to be followed continuously as Earth rotates, the network of listening stations must be worldwide.

Viking's terrestrial systems are three in number: (1) the launch and flight operations system, (2) the tracking and data system, and (3) the mission control and computing center system. The facilities that make up these systems—Kennedy Space Center, DSN, and JPL's Space Flight Operations Facility (SFOF)—are multipurpose. All NASA's interplanetary and lunar missions utilize them.

Viking will be launched at the Kennedy Space Center from Launch Complex 41. This is part of NASA's Integrate-Transfer-Launch Facility at the Cape (fig. 27). The vertical integration building will be used to assemble the liquid rocket Titan core and the Centaur upper stage. The mated liquid stages will then be transported by rail to the solid motor assembly building where the two big solid rocket stages will be attached. The entire launch vehicle will then move by rail to the launchpad. Rail-mounted vans containing necessary checkout equipment will follow. At the launchpad, the spacecraft will be mated to the Centaur and enclosed in the Centaur standard shroud. Following exhaustive tests and checkout, the spacecraft and launch vehicle will be ready to go.

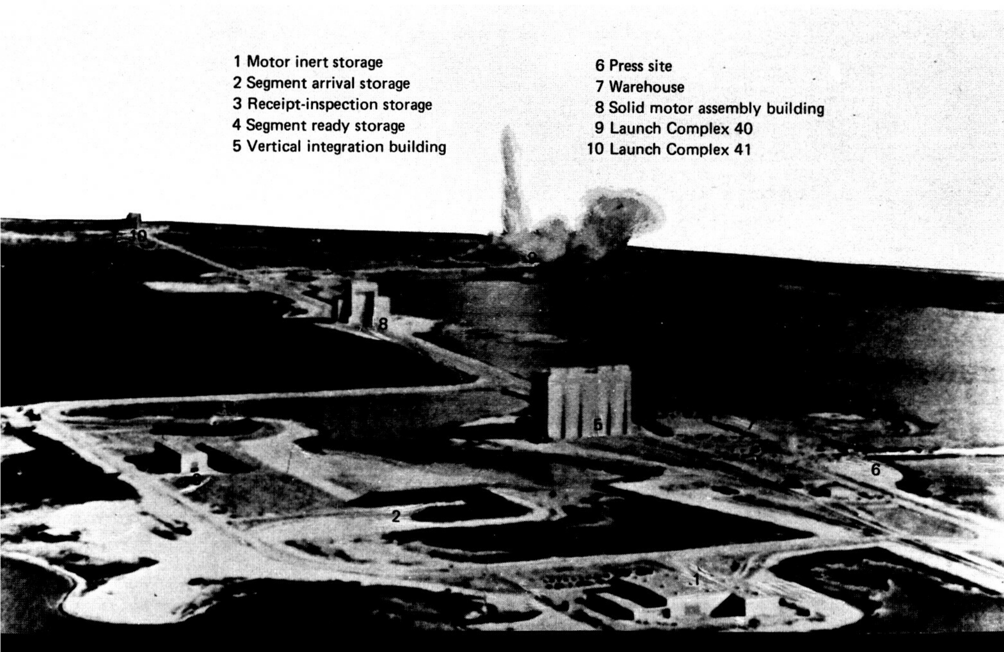
At Cape Canaveral and on islands, ships, and planes along the Air Force's Eastern Test Range (ETR), radars and optical tracking instruments will follow the launch vehicle as it rises from the pad and heads downrange toward Ascension Island in the South Atlantic. ETR will

continue to receive telemetry data from the Viking spacecraft until it separates from the Centaur. When the spacecraft is separated from the Centaur its radio signal will be received by the DSN stations. From that moment on, the DSN's tasks are to track Viking, receive its telemetry, and send commands to it.

The DSN is a worldwide tracking and data acquisition facility consisting of six 26-meter (85-foot) paraboloidal antennas and three 64-meter (210-foot) dishes (fig. 28). The 64-meter dishes are critical to Viking, for only they are sensitive enough to receive Viking data from Mars at sufficiently high rates. These paraboloids are spaced around Earth so that one will always have Mars in view. Their locations are in Goldstone, Calif.; Madrid, Spain; and Tidbinbilla, Australia (fig. 29). Amplifiers at the foci of the antennas are cryogenically cooled to reduce thermally induced noise. Each site was selected on the basis of lack of manmade radio noise. Only with antennas of such size, carefully designed and sited, can the faint radio signals of the Viking transmitters be heard over distances exceeding 200 million miles.

The DSN stations are tied together by a global communications network called the NASA communications network, which uses cables, microwave relays, and satellites to feed signals to the SFOF at Pasadena, Calif. (fig. 30). An impressive, four-level structure, the SFOF is a multimission terminal, data-processing facility, computer center, and control center from which mission operations are controlled. A portion of the SFOF will be turned over to the Viking program. Another part of the Viking flight team, science analysis and evaluation, will be located in an adjacent building. In total, the flight team consists of about 700 members.

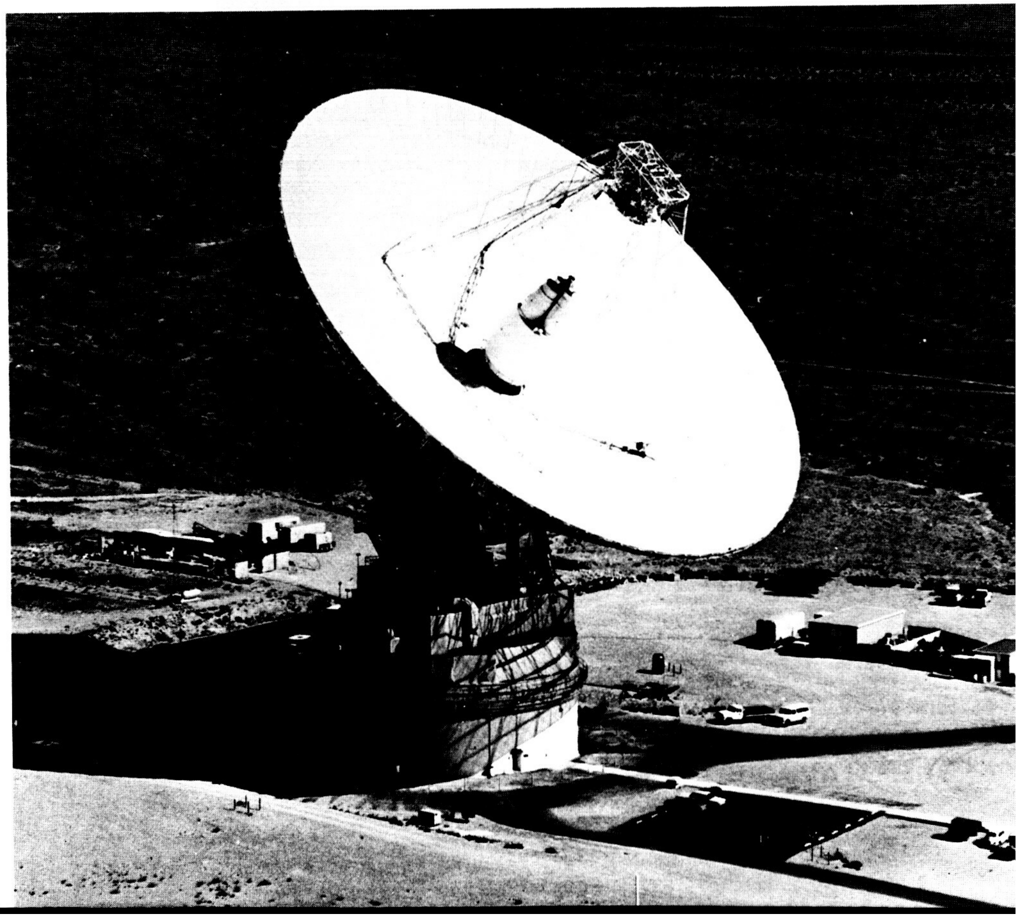
FIGURE 27.—Integrate-Transfer-Launch Facility.



(*a*)

FIGURE 28.—DSN antennas. (*a*) 26-meter antenna. (*b*) 64-meter antenna.

(*b*)



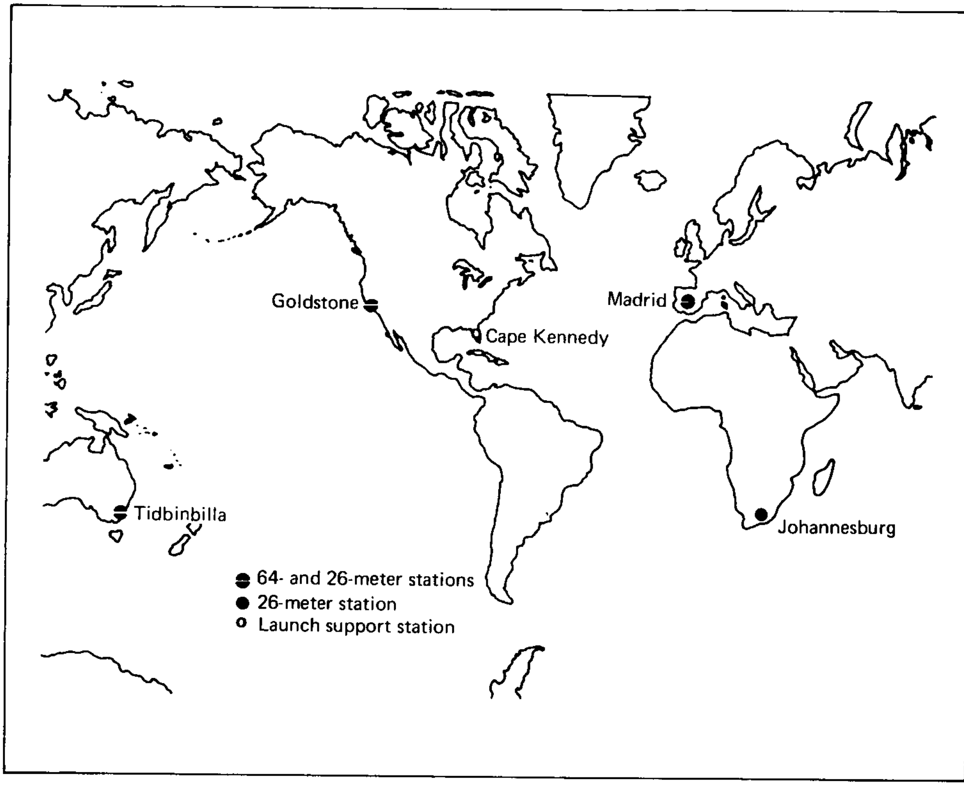


FIGURE 29.—Location of DSN stations.

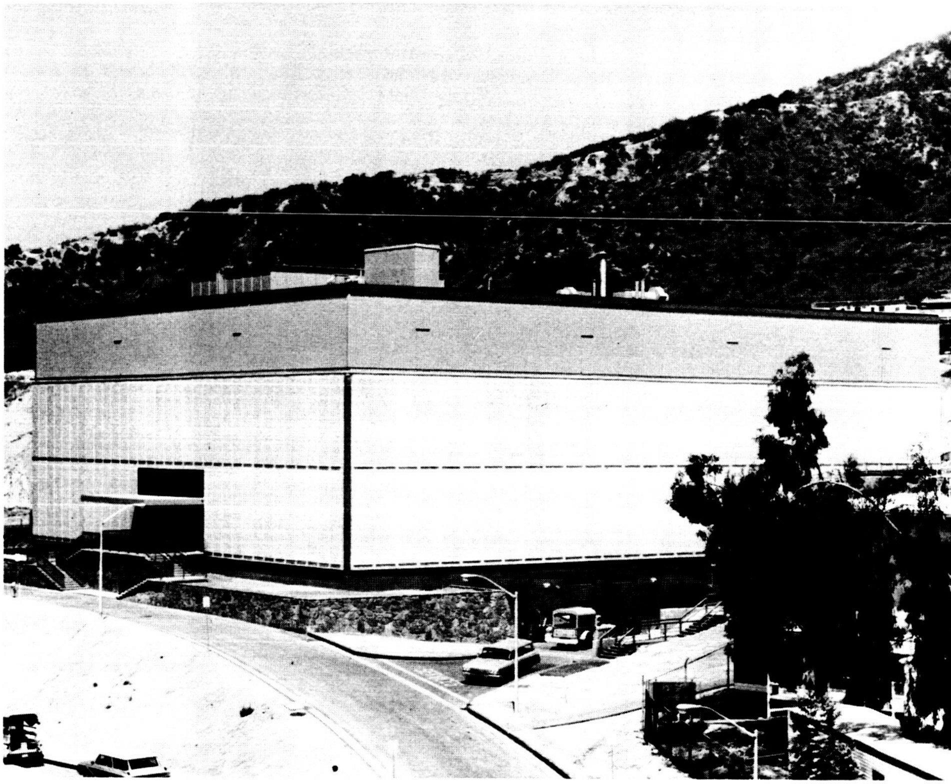


FIGURE 30.—Space Flight Operations Facility.

Chapter 5 Viking Scientific Explorations

The View From Orbit

Three types of optical instruments view the surface of Mars from the Orbiter's scan platform (fig. 31). These are a pair of high-resolution television cameras, an infrared atmospheric water detector, and an infrared radiometer for atmospheric and surface thermal mapping. Together the instruments scan strips of the surface below as the Orbiter swings around Mars. The infrared instruments will pinpoint warm, wet places. These sites can then be checked visually for geological interest and suitability for landing, using the photographs taken at the same time.

Once the Lander is on the surface, large-scale observations from the Orbiter—say, the detection of an oncoming duststorm or other regional changes detectable from orbit—may be correlated with fine-scale measurements obtained by the Lander as the phenomenon sweeps over it.

The Orbiter Cameras

Each of the two Orbiter television cameras consists of a 1.5-inch vidicon, telescope, mechanical shutter, and filter wheel (fig. 32). When the shutter of the camera is open, an electrostatic image of the scene below is formed photoelectrically on the vidicon target material, which is then scanned by an electron beam. Neutralization by the beam converts the image into electrical signals. Each image (or frame) consists of 1056 lines of 1182 spots (pixels). The intensity of each spot or pixel is transmitted as a seven-bit word. Thus, each transmitted frame consists of 8.7 million bits. Each frame is scanned every 4.48 seconds. A wheel incorporating seven different filters can be turned by command to admit light from different portions of the spectrum over the 3600- to 6500-angstrom range.

The camera axes are canted slightly so that a pair of pictures covers a solid angle 3.1° by 1.51°. During actual operation each camera takes one picture every 4.48 seconds, one camera "reading" its image, the other erasing its last one. At an altitude of 1500 kilometers the cameras photograph contiguous, nonoverlapping squares 80 kilometers on a side in swaths about 500 kilometers long. Resolution will be about 40 meters

under these conditions, capable of resolving an object the size of a football stadium.

Vidicon cameras are susceptible to changes in their response to light. Just prior to Mars encounter, while the spacecraft is still in "celestial lock" (that is, its navigation sensors are still locked onto the Sun and Canopus), the cameras will take pictures of known stars for calibration purposes. A few exploratory pictures will also be taken of Mars to see if there have been any large-scale surface changes since the Mariner 9 photographs were taken.

The prelanding period will be devoted almost exclusively to checking out the potential landing sites. Emphasis will be on mapping and geologically detailing the likely spots. Following a successful landing, the Orbiter's periapsis will be kept near the landing site to make data relaying easier. During this period the cameras will be on the lookout for changes in the atmosphere and on the surface. Ultimately, the Orbiter will be released from the Lander-support task and its orbit will be varied for more comprehensive studies of the planet.

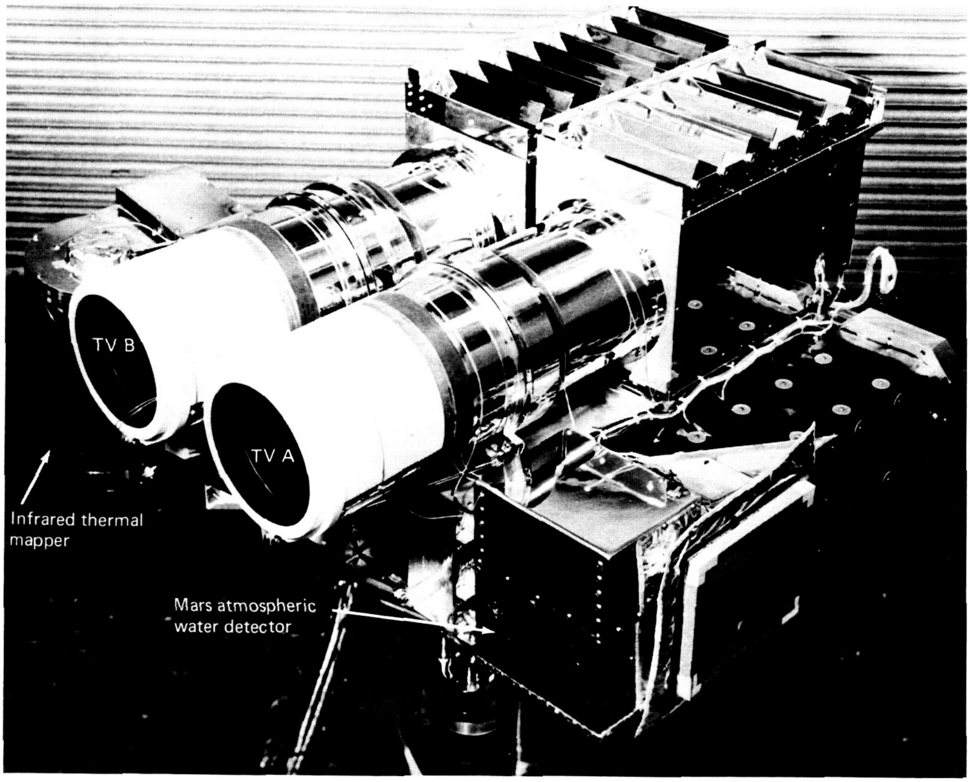


FIGURE 31.—Orbiter science scan platform.

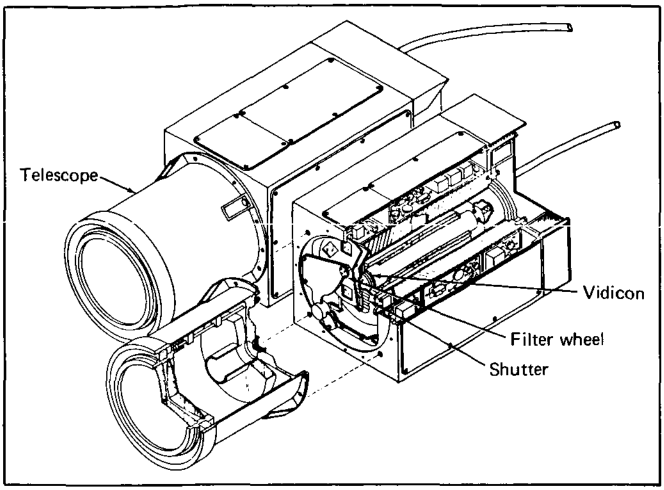


FIGURE 32.—Orbiter visual imaging subsystem.

Mapping Concentrations of Water Vapor

More than anything else, Viking will be looking for signs of life on Mars, and in terrestrial thinking this means water. The presence of this biologically important substance should, therefore, be a factor in selection of the final landing site. Mariner 9 photos leave little doubt that liquid water has existed on the surface of Mars in the past. The atmospheric conditions under which some of the Martian clouds prevail indicate that they are formed from water ice crystals. The objective of the Mars atmospheric water detector (MAWD) is to locate areas of the surface where the concentration of water vapor (and by inference, ground water, probably as ice or permafrost) is high. This information will then be weighed with data on the terrain, geology, and temperature in making the final landing-site decision.

Once the Orbiter has been released from its landing-site duties, the MAWD can inquire into planetwide variations of water-vapor concentration, particularly in connection with geological features and the diurnal cycle. Martian meteorology has become unexpectedly interesting, and water vapor is a key factor on this unusual planet. Present atmospheric conditions inhibit the accumulation of large bodies of water as on Earth. The hydrologic cycle of Mars is different from that of Earth and what possibly existed on Mars in the past.

Water vapor is detected from orbit with an infrared spectrometer sensitive to the absorption band of water vapor existing at approximately 1.38-micrometer wavelength. Traces of water in the Martian atmosphere were first detected from Earth in this way in 1965. The optical configuration of the MAWD is shown in figure 33. Infrared radiation reflected from and emitted by the Martian surface passes upward through the

atmosphere into the MAWD. Passing through a chopper, it is collimated and reflected back to a 12,000-line-per-centimeter grating which spreads out the spectrum onto an array of five lead sulfide infrared detectors. Three of these detectors are located so that they intercept wavelengths in the absorption band of water vapor near 1.38 micrometers; the other two are on either side of the band for reference purposes. The relative amount of infrared radiation detected by those sensors in the absorption band and outside it will be related to the amount of atmospheric water vapor the light has passed through. The chopper provides an alternating signal that is much easier to amplify than a steady signal.

The raster mirror indicated in the optical diagram is driven through a cycle of 15 steps by a small motor. This motion permits the instrument to scan terrain transverse to the Orbiter's motion. Fifteen staggered rectangles 3.0 by 24 kilometers are seen each sweep. A very crude 15-line "picture" of water-vapor concentration is thus formed every 4.48 seconds. The sensitivity of the MAWD is about 1 precipitable micrometer of water. In other words, if the total amount of water vapor in the column of "air" under the Orbiter increases by 1 micrometer when condensed to liquid, the MAWD will detect this change.

Although the principles are simple, the instrument itself is sophisticated and rather large. The optical portion is 71 by 20 by 28 centimeters (28 by 8 by 11 inches). Alinement is critical, and the MAWD must be rugged to preserve alinement during launch and temperature variations. The entire instrument, including the supporting electronics, weighs 15.9 kilograms (35 pounds).

Looking for Hot Spots

Another desirable feature of a landing site is warmth, for life, if present, would likely favor warm niches. A thermal map of the Martian surface will also give us much-needed information on cold spots and the temperatures of frost layers and the tops of clouds. These data will help explain condensation occurring in the atmosphere and perhaps help account for the fierce winds which whip up the colossal Martian duststorms. Geologists are, of course, interested in any hot spots detected because they are diagnostic (on Earth, at least) for geologically active areas such as volcanoes and hot springs.

The Viking Orbiter's infrared thermal mapper (IRTM) measures the infrared brightness of the surface below in several spectral bands or channels. The spectrum of radiation emitted by a surface—even a surface as cold as Mars—depends strongly on its temperature. Of course, corrections have to be made for reflected solar radiation. In addition, the surface emissivity depends on its composition and roughness. Previous work with Mariners and similar instruments on Earth weather satellites has given scientists considerable experience in translating radiation measurements into surface and cloud temperatures.

The IRTM is a four-channel infrared radiometer:

(1) 6 to 8 micrometers
(2) 8 to 9.5 micrometers
(3) 9.5 to 13 micrometers
(4) 18 to 24 micrometers

Additional channels for measuring the atmospheric temperature and the reflected radiation (albedo) are at 16 micrometers and 0.3 to 3 micrometers, respectively. A radiometer, such as the IRTM, does not disperse the spectrum with a grating or prism. Instead, the desired portions of the spectrum are selected by filters. The Orbiter IRTM consists of four telescopes, each with interference-type filters which pass radiation in only the channels listed (fig. 34). Bimetallic thermopiles sensitive to infrared radiation measure the quantity of radiation in the spectral intervals passed by the filters.

In the Viking IRTM, each channel uses seven antimony-bismuth detectors arranged in a chevron pattern. Each detector views the Martian surface through a 0.3° field of view, which, at an altitude of 1500 kil-

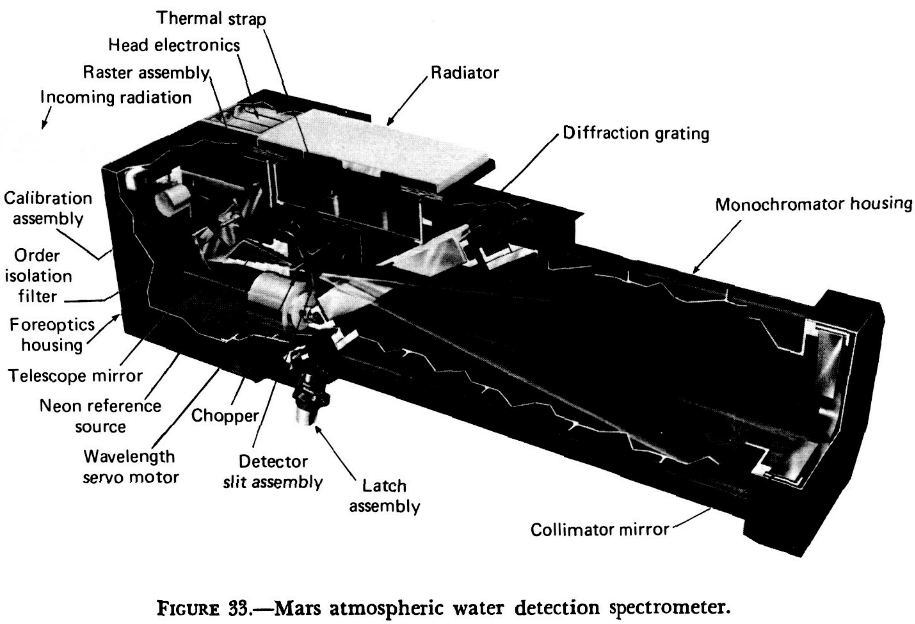


FIGURE 33.—Mars atmospheric water detection spectrometer.

ometers, is equivalent to an 8-kilometer circle on the ground. The temperature resolution of channels (1) to (3) is less than 0.1° C; that of channel (4) is 0.36° C. The scan mirror shown in figure 34 is stepped systematically through three positions: one position allows the instrument to view the planet surface; a second brings into view a reference surface at a known temperature; the third position points the detectors at deep space. A complete cycle lasts about 1.25 minutes. The scan mir-

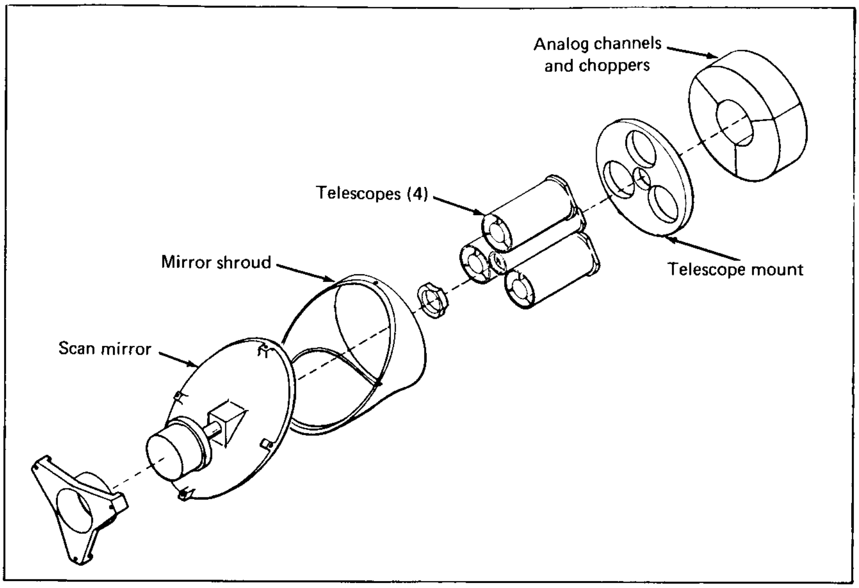


FIGURE 34.—Orbiter IRTM layout. (*a*) Exploded view.

ror has nothing to do with scanning the terrain; rather, it is the motion of the scan platform which brings each segment of terrain in the swath below into view of the staggered detectors, one channel after another.

Experiments During Atmospheric Entry

Previous Mariners made indirect measurements of the thin layer of gases surrounding Mars, with unexpected results. Mars has a very cold lower atmosphere consisting almost entirely of carbon dioxide rather than nitrogen as was earlier supposed. In addition, radio-propagation experiments have indicated that a thin but fairly dense ionosphere exists at approximately 130 kilometers. None of the Mariners came closer than 1300 kilometers to the surface. Direct confirmation by *in situ* measurements would be highly desirable. The Viking Lander will plunge through the ionosphere and atmosphere, giving scientists a few precious minutes to sample the ions, atoms, and molecules directly.

A retarding potential analyzer and a mass spectrometer will be mounted on the aeroshell forward surface. Three other instruments will provide additional atmospheric data less directly. They are a pressure cell, a sensor to measure the temperature, and the accelerometers in the inertial reference unit (fig. 35). These instruments are concerned primarily with the aerodynamic properties of the Martian atmosphere, but will indirectly tell us much about atmospheric density and pressure when the atmosphere begins to slow the Lander.

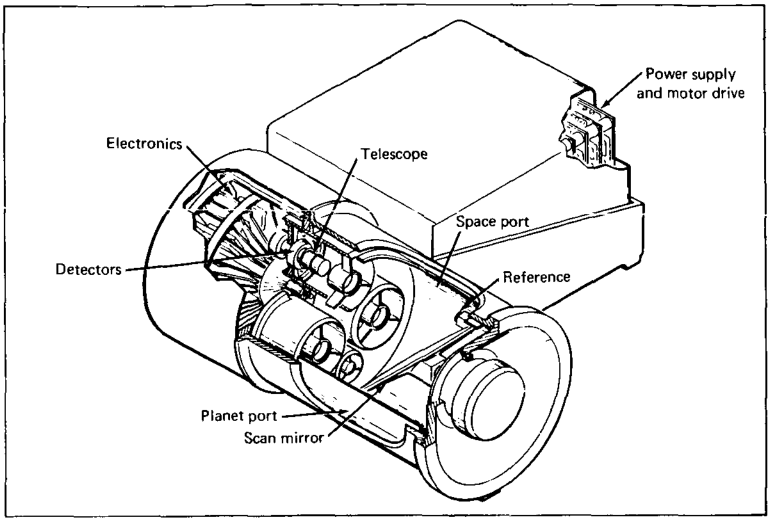


FIGURE 34.—Continued— (*b*) Cutaway view.

Retarding Potential Analyzer

Scientists are puzzled about electrical processes transpiring in the upper atmosphere of Mars. Sunlight dissociates some of the carbon dioxide to create an ionosphere, but how does the solar wind interact? Does Mars possess a sufficient magnetic field to ward off the solar wind before it can interact directly with the atmosphere? Or do the high-velocity solar-wind ions penetrate deep into the atmosphere?

Retarding potential analyzers have been flown on many Earth satellites and space probes. Basically, they are made from a series of wire grids like those in an old-fashioned vacuum tube (fig. 36). As the voltage on the grids is swept through a range of positive and negative voltages, varying portions of the population of ions and electrons in the outside atmosphere will penetrate the grid structure. The current of electrically charged particles traversing the grids will be measured by a sensitive electrometer. In essence, the grids act as an electrical filter which admits only those particles possessing selected ranges of energies and electrical charge.

The retarding potential analyzer is located near the edge of the aeroshell. Its aperture is a 3.8-centimeter (1.5-inch) diameter circle (fig. 36). The first, second, and last of the six grids are grounded to the spacecraft. The third and fourth grids are connected electrically and make up the so-called retarding grid. The fifth grid acts as a suppressor. The 4-second instrument cycle consists of three voltage sweeps applied to the retarding grid: 15 to 0 volts in 2 seconds, −75 to 0 volts in 1 second; and −1.5 to 0 volts in 1 second. In this way, wide

ranges of ions and electrons are sampled during the penetration of the ionosphere and lower atmosphere. The analyzer will be effective for particle concentrations between 10 and 10^6 particles per cubic centimeter.

Mass Spectrometer

Most of the particles in the Martian atmosphere are electrically neutral. Scientists need to know their identities and concentrations as a function of altitude to understand the chemistry and thermal structure of the atmosphere. The mass spectrometer is the appropriate instrument here, and once again considerable pioneering work has already been done on scientific satellites, but there are important differences between the Viking and typical satellite missions. Viking's measurements must be made quickly during the short entry phase; the Martian atmosphere is very thin and measurements will be made at high spacecraft speeds.

A schematic diagram of the Viking mass spectrometer is shown in figure 37. As the aeroshell pushes into the sensible atmosphere, gas flows into the instrument. A beam of electrons created by the instrument bombards the incoming neutral atoms and molecules and ionizes them. These ions are first accelerated by grids and then pass through a slit into a region bounded by two parallel plates. One is at a negative voltage, the other at a positive voltage. Emerging from between the

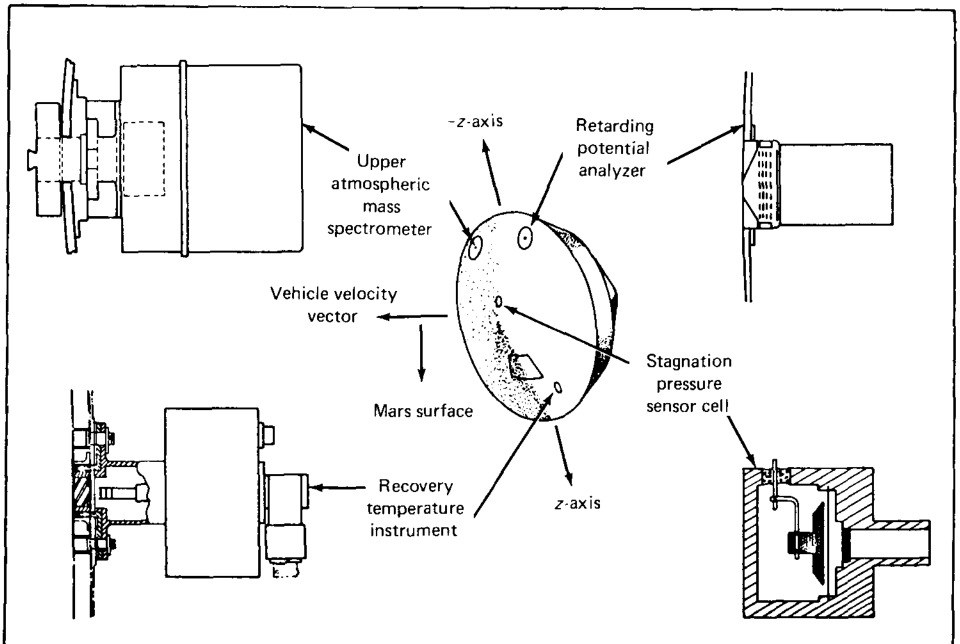


FIGURE 35.—Entry sciences aeroshell instrumentation. (Accelerometers are located internally in the inertial guidance unit of the guidance and control system.)

plates, the ions enter a fixed magnetic field which makes them curve toward two ion collectors. The electrostatic and magnetic fields work together to focus ions with certain electrostatic charges and momentum. For this reason, this type of instrument is called a double-focusing mass spectrometer. For a given combination of accelerating voltage and potential difference across the plates, two groups of ions, each with certain masses, will be focused into the two collectors. By sweeping the accelerating voltage and the potential difference across the plates, the instrument will measure ions from 1 through 50 atomic mass units. One collector handles the atomic mass unit range from 1 to 7, the other covers the range from 7 to 49 atomic mass units. The spectrum will be swept every 5 seconds during entry.

The range of the mass spectrometer is broad enough to measure carbon (12 atomic mass units), oxygen (16 atomic mass units), carbon monoxide (28 atomic mass units), and carbon dioxide (44 atomic mass units). All of these should be present in a predominantly carbon dioxide

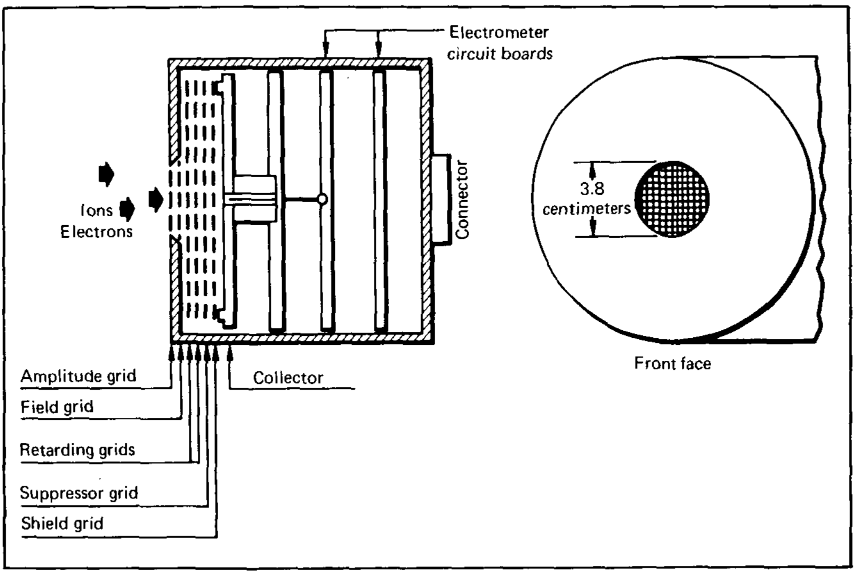


FIGURE 36.—Retarding potential analyzer.

atmosphere subjected to bombardment by solar radiation and dissociation through mutual collisions.

Surface Science

Strategy for a Martian Laboratory

Once Viking lands on the Martian surface after years of work by thousands of scientists and engineers, it would be tempting to turn on

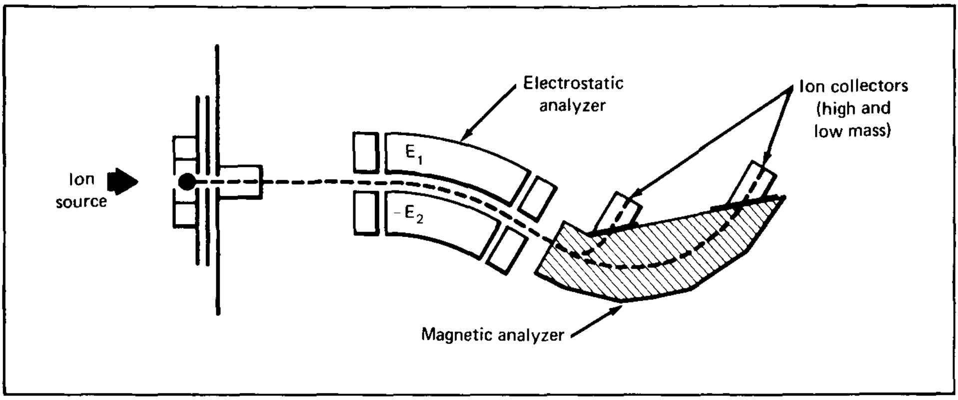


FIGURE 37.—Double-focusing mass spectrometer.

at once all the instruments to learn as much as we could about this intriguing planet. This impulsive approach would be self-defeating because the instruments are interdependent and experiments must be done carefully and, above all, in the right order. Clearly an experimental strategy is essential.

The Viking science strategy is not fully worked out yet, but some preliminary thoughts can be presented. For example, no matter how well conceived the engine design, the rocket descent is bound to stir up the surface to some degree. Some of the experimentation must wait for the dust to settle. A second delaying factor involves the engine gases liberated during descent. No atmospheric samples should be taken for several days to avoid detecting "the breath of the spacecraft."

Would just a look around with the camera hurt? It might if high-velocity winds flung sand against camera lenses, sandblasting them to the point of uselessness. Consequently, present strategy calls for one of the two cameras to be used approximately 10 minutes after landing to obtain visual imaging data, while the second camera will not be used until the meteorology instruments check and report the weather. Experiments with the mass spectrometer and biology instrument must also be carefully planned.

Imaging data of the sample area must be obtained to assure that the sample acquisition boom can safely acquire the sample. Soil samples cannot be analyzed while waiting for the air to clear of spacecraft effluents because the soil would contaminate the instrument for later atmospheric analysis.

The final science strategy will manifest itself in a long series of preprogramed instructions stored in the computer's memory. This predetermined strategy may be altered upon command from Earth if adequate communications have been established. The high degree of automation insures that experiments will progress even in the face of initial communication problems.

A good deal of forethought has succeeded in locating the scientific instruments where their measurements are not influenced by other experiments or the presence of the Lander. Most of the chosen locations can be seen in the external view of the Lander (fig. 23). The schematic of inlet/outlet locations (fig. 38), however, reveals some of the problems. The gas and liquid vents from the experiments must not be placed near any inlets or the sample acquisition area. Also, meteorology instruments should be mounted where they are not affected by effluents or wind disturbance caused by the antenna. Another type of interaction is mechanical—spacecraft motors must be off when the seismometer is on.

The science strategy must also include the two Orbiters and another Lander elsewhere on the surface. The Orbiter observations of storms and other dynamic processes can be correlated with Lander measurements. Even the Landers can help each other in the sense of providing a stereophonic view of seismic events and surface weather.

A Look Around the Spacecraft

Camera eyes on Mars have exciting work to do. Their assignments include inspecting the geology of the landing site, observing duststorms and clouds, following the Martian satellites as they move swiftly across the horizon, and, most important, searching for possible Martian life in living or fossilized forms.

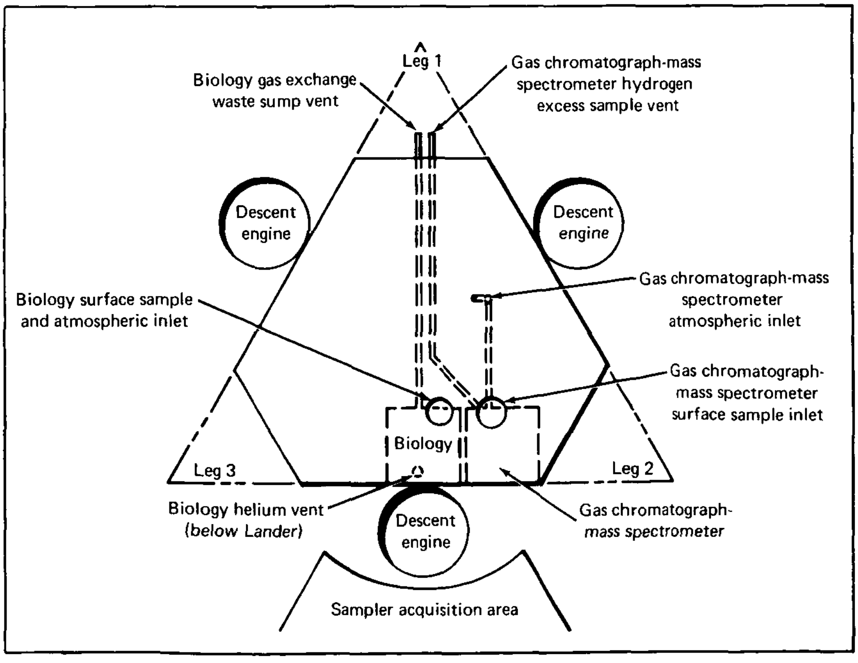


FIGURE 38.—Landed science inlet/outlet locations.

The two stereoscopic cameras are mounted on top of the Lander frame where they can take 360° panoramic pictures of the landing site. They can scan upward from the Lander footpad to about 40° above the horizon. This extensive coverage is accomplished with the help of a scanning mirror that nods up and down and with rotation of the camera as a whole.

The optical image is not formed as it is on the Orbiter's vidicon plate. Rather, the outside scene is dissected pixel by pixel by the mechanical motions of the scanning mirror and turret action of the camera (fig. 39). The image is formed only when all the pixels are assembled into a picture back on Earth. The principle is like that used in transmitting newspaper pictures by facsimile.

This type of camera can be made surprisingly versatile. Light admitted through the lens falls on an array of a dozen pinholes, each backed by a photosensor. Each photosensor generates a signal propor-

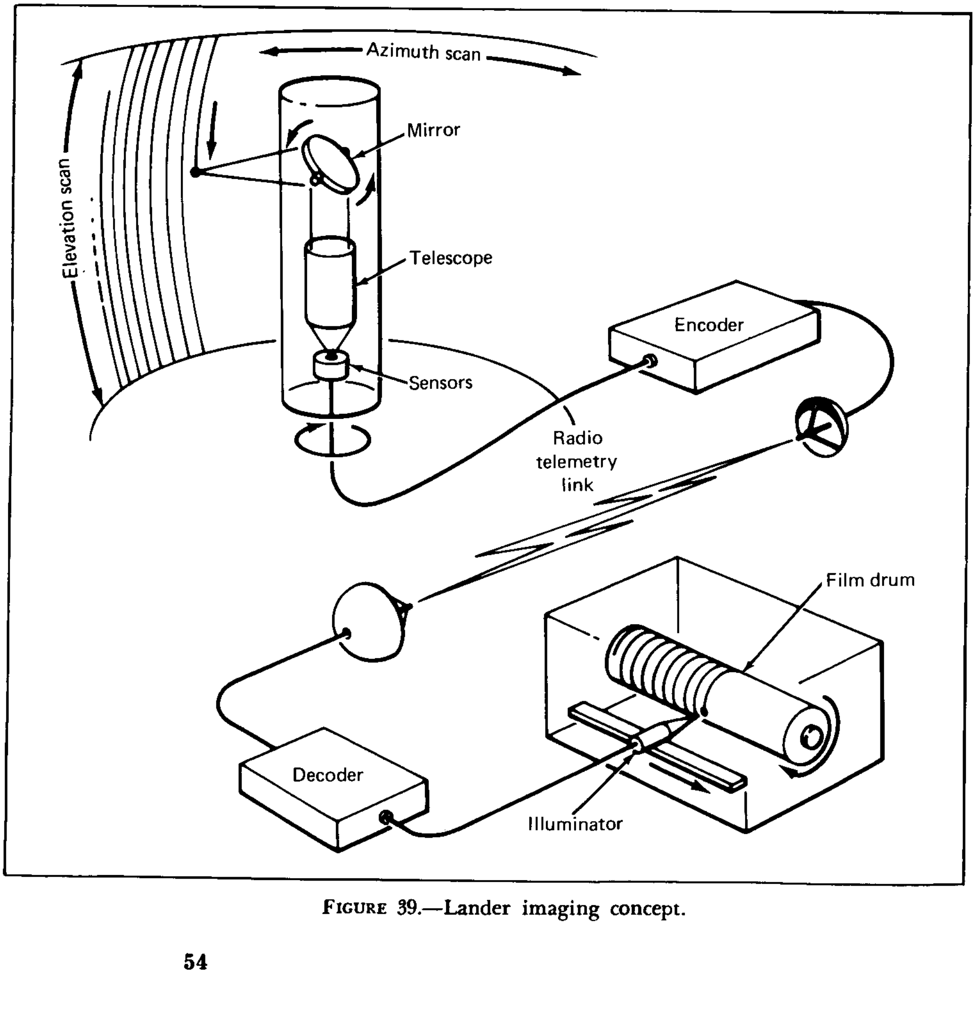


FIGURE 39.—Lander imaging concept.

tional to the amount of light falling on it. At any instant, any one of the pinhole-sensor combinations can create a pixel of the scene being surveyed. By using filters, colored pictures can be achieved. By adjusting the distance between the lens and the sensors, objects at various distances can be focused. Resolution near the footpad is a few millimeters and decreases with increasing distance to the object.

The cameras can scan at two rates, one matched to the ultrahigh frequency link to the Orbiter, 16,000 bits per second, and the other to the direct link to the Earth, 250 bits per second. The Lander cameras, like those on the Orbiter, generate data at a tremendous rate: 10 million bits for a single complete panorama around the spacecraft with a 60° scan in elevation. A similar picture in color would take three times as many bits; high resolution photography, even more.

Automated Chemical Analyses

Three kinds of scientific investigations call for chemical analysis. We want to know the chemical composition of the atmosphere and we want to analyze the soil around the Lander for organic and inorganic chemicals. These experiments can tell us much about the likelihood of life on Mars—past, present, or future—and about the geological differentiating that has occurred on the planet. This is because chemical evolution precedes biological evolution. Even if the Lander's biological experiments fail to detect life in the immediate vicinity, the composition of the atmosphere and soil may preserve echoes of past life or the precursors of future life.

The mass spectrometer is the best choice for atmospheric analysis once on the surface. As in the mass spectrometer employed during the entry phase, atmospheric molecules admitted to the instrument are ionized and then separated according to their masses by electromagnetic means. However, solid samples picked up from the surface must first be volatilized. Solids will, therefore, first be transferred to an oven and heated to volatilize and ultimately pyrolyze contained organic compounds. Then the resultant gases will enter a chromatographic column that separates various compounds by using the fact that different organic gases travel at different speeds through the materials packed in the column. As the separated gases emerge from the chromatograph, they are fed into the mass spectrometer for identification. It is obvious now why atmospheric analysis must precede the study of solid samples—the organic gases may contaminate the mass spectrometer. The schematic for the Viking gas chromatograph-mass spectrometer (GCMS) is shown in figure 40.

The operating principle of the Lander's mass spectrometer is similar to that used for entry experiments. Both are of the double-focusing type. The mass range, though, must be much larger for the Lander in which the goal is to detect the heavier molecules resulting from the

heating of organic compounds. From an engineering standpoint, it is difficult to build this type mass spectrometer to cover both the very low and the higher mass numbers. It was therefore decided to ignore hydrogen and helium and concentrate on the range from 12 to 200 atomic mass units. Compounds containing up to 10 carbon atoms can be accommodated in this range. Most atmospheric molecules will also be within range.

During atmospheric analysis, gas samples will first pass through a chemical filter capable of absorbing all of the carbon monoxide and carbon dioxide. This means that well over 90 percent of the sample will be eliminated before it enters the spectrometer, permitting the analysis to be concentrated on the more interesting minor constituents, such as oxygen, nitrogen, argon, and krypton. The chemical filter, possessing a limited absorption capability, sets a limit of about 60 sample analyses. Unfiltered analyses will also be made to observe the relative abundance of the more prevalent gases and water vapor.

Gases are far easier to handle than solids. Analysis of solids proceeds thus: First a soil sample of approximately 100 milligrams is deposited in one of several little ovens on a motor-driven holder. Then, the oven is electrically heated to about 200° C. If the sample is rich in organic compounds, many gases will evolve. If the sample is organically poor, there will be little evolution, and the temperature may have to be raised to 350° C or even 500° C. The higher the temperature the more the sample will be volatilized or pyrolyzed. Since high temperatures destroy the more complex organic molecules, low oven temperatures are applied first.

A stream of stored hydrogen carrier gas sweeps any evolving gases from the oven into the gas chromatograph column. This is simply a long tube packed with coated beads or other solids that selectively delay the passage of different gases in accordance with their adsorptive properties. Another feature of the GCMS is the "splitter," which diverts excess gas from the mass spectrometer to prevent overloading the ion pump (a device used to remove ions from the gas sample to achieve the low operating pressure required). The hydrogen carrier gas is also separated at this point.

Present plans call for making two analyses for each of three soil samples. The surface sampler will, of course, scoop these up from the most interesting areas seen through the cameras.

The inorganic and elemental analysis (described in more detail later) is not a primary part of the analyses supporting the biological investigation; however, the data acquired from this analysis are of interest to the biologists and could aid in interpreting the results of their investigation.

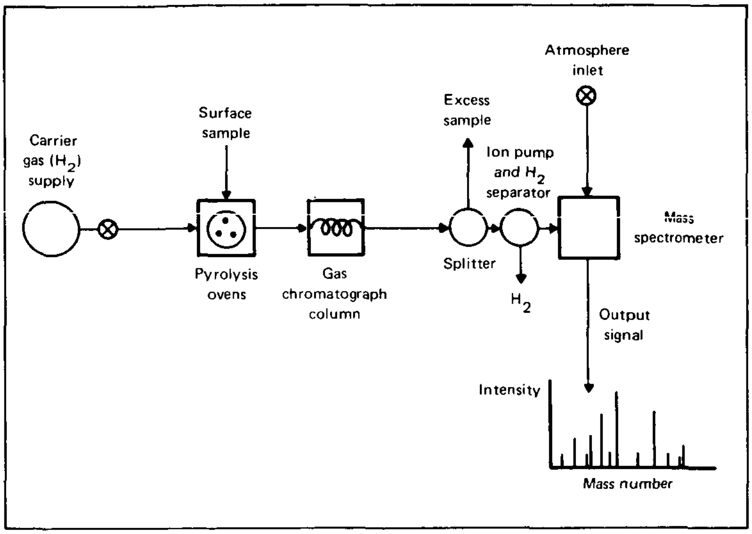


FIGURE 40.—Gas chromatograph-mass spectrometer schematic.

The Life Detectors

While the Lander cameras may spot some unmistakable form of life, it now seems much more probable that Martian life, if it exists, will be in the form of micro-organisms. During the past two decades, many ingenious schemes have been devised for remotely detecting the presence of micro-organisms on other planets. Most techniques involve detecting the processes of metabolism and growth common to Earth life (and which are expected to be common to Martian life, too). Viking scientists have selected three approaches:

(1) *Pyrolytic release experiment:* A sample of soil is dumped into a chamber where the Martian environment is simulated in all aspects, except that some of the normal carbon dioxide atmosphere is replaced by one of carbon monoxide and carbon dioxide "tagged" with radioactive carbon-14 (fig. 41). Water vapor can be added upon command. Any life in the sample should assimilate some of this artificial atmosphere and incorporate the radioactive atoms into the organic compounds it manufactures—assuming its behavior is like that of Earth organisms. Artificial sunlight from a xenon lamp will bathe the sample to promote photosynthesis should these micro-organisms be plantlike. After several days' incubation, the sample will be pyrolyzed at about 600° C to drive off organic vapors. The vapors will be separated by a special copper-oxide vapor trap and monitored for radioactivity. The presence of radioactive

FIGURE 41.—Pyrolytic release experiment.

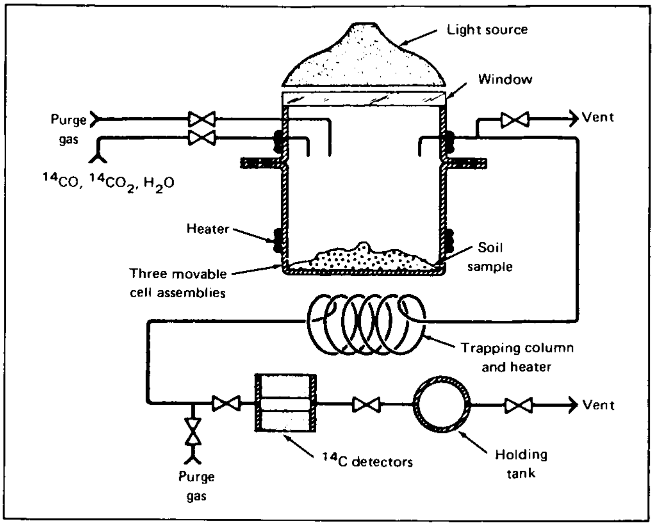


FIGURE 42.—Labeled release experiment.

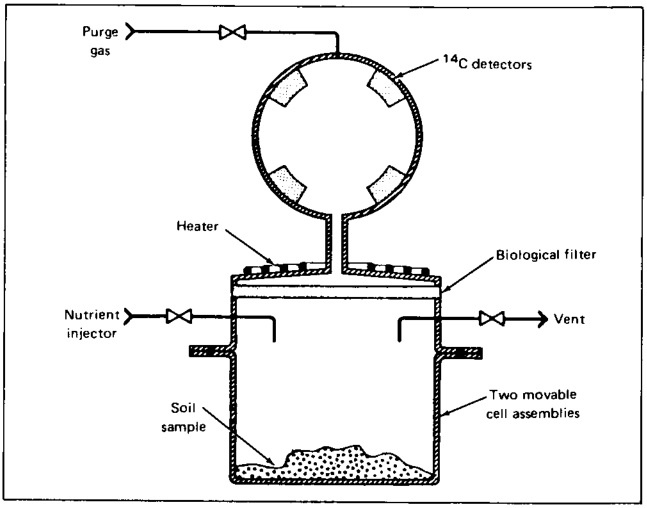
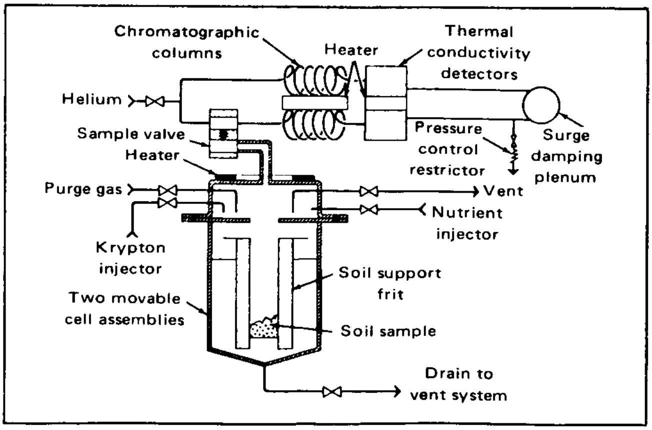


FIGURE 43.—Gas exchange experiment.



organic molecules would strongly imply terrestrial-type metabolism in the sample. An important feature of this experiment is that it is performed under essentially Martian conditions and that Martian life, if present, will not be destroyed before it can be detected.

(2) *Labeled release experiment:* Similar in principle to the foregoing experiment, this one substitutes carbon-14-tagged nutrients for the tagged atmosphere. A soil sample will be moistened by a small sample of tagged nutrients and then incubated; that is, given time to assimilate the nutrients. Any tagged carbon dioxide or tagged volatiles released during incubation would imply the existence of metabolism. By measuring the amount of tagged gases excreted as a function of time, information on the reproduction rate and physiological state of the micro-organisms may be obtained. This type of life detector has been successfully tested in several desolate but life-sustaining terrestrial environments (fig. 42).

(3) *Gas exchange experiment:* This experiment is based on the fact that the atmosphere over a sample containing metabolizing micro-organisms changes in composition with time. A soil sample will first be moistened with a rich nutrient. Periodically, after suitable incubation, samples of the atmosphere will be conveyed to a gas chromatograph to discover whether any chemical changes have occurred. Methane and carbon dioxide are likely products of micro-organisms growing in a dark, oxygenless environment; and if the concentrations of gases such as these change during incubation, it will be evidence for the presence of living material in the sample (fig. 43).

It is much easier to draw the schematic diagrams of these instruments than to build the requisite mechanical and chemical apparatus. The collection of a sample, its preparation, and its transportation to the experiments are exceedingly difficult to automate. The biology experiments really constitute three tiny, separate laboratories that must handle gases, liquids, and solids reliably on the surface of a distant planet. The prototype model of the integrated instruments (fig. 44) reflects the complexity of the engineering job.

Life detection is a new branch of biology. Its practitioners know what to look for on Earth, but they will be at a serious disadvantage on Mars. Mars life may be radically different from what scientists anticipate. The Viking experiments may not ask the right questions, so a "no" from each of the three experiments would not rule out Martian life completely. In addition, life on Mars may be highly localized in specialized niches—niches that terrestrial biologists might not consider hospitable at all, or that might be inaccessible to the sampler.

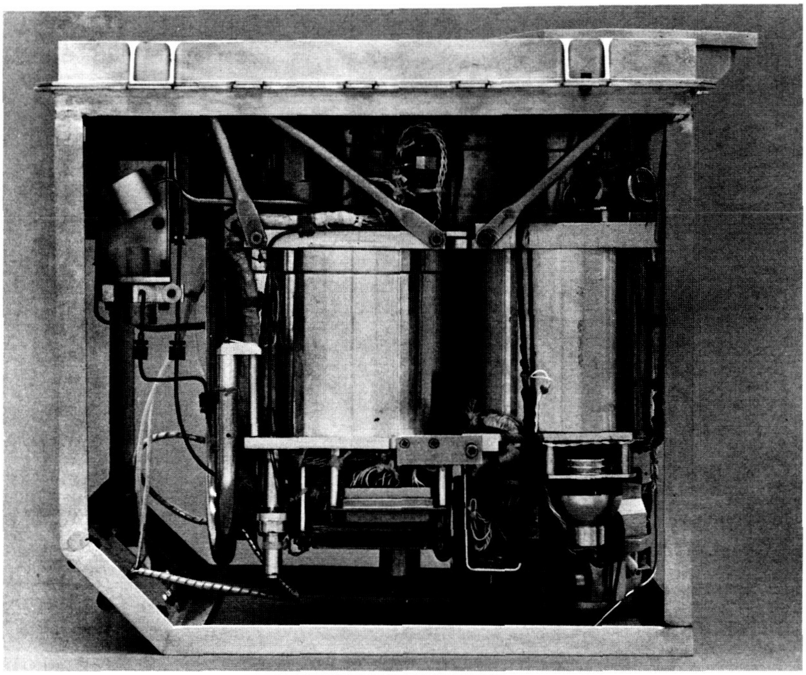


FIGURE 44.—Biology experiment prototype model.

What Is the Surface Made Of?

The preceding experiments are concerned primarily with the chemical evolution leading up to life. Scientists interested in the evolution of the solar system are also anxious to study the inorganic portion of the Martian surface; that is, the mineralogy of the sand, rocks, or whatever constitutes the surface material. We now have extensive data on two bodies of the solar system: Earth and the Moon. Knowing the constituents of the Martian surface would give us a great deal more insight about how the inner terrestrial-type planets evolved.

The return of rock samples to Earth from Mars may be accomplished eventually by unmanned spacecraft—as it has been done for the Moon by the Russians—but this is beyond Viking's capabilities, so analysis will have to be done remotely. When only the abundance of the elements is required (as opposed to molecular analysis), some comparatively simple instrumentation from the physics lab works well. The physical technique selected for Viking is X-ray fluorescence. In this approach, the sample is bombarded by X-rays from radioactive elements. The X-rays activate atoms in the sample and induce them to emit X-rays themselves. (This is fluorescence.) The emitted X-rays are characteristic of the elements in the sample; each element has in effect its own X-ray fingerprint. By measuring the numbers and energies of the

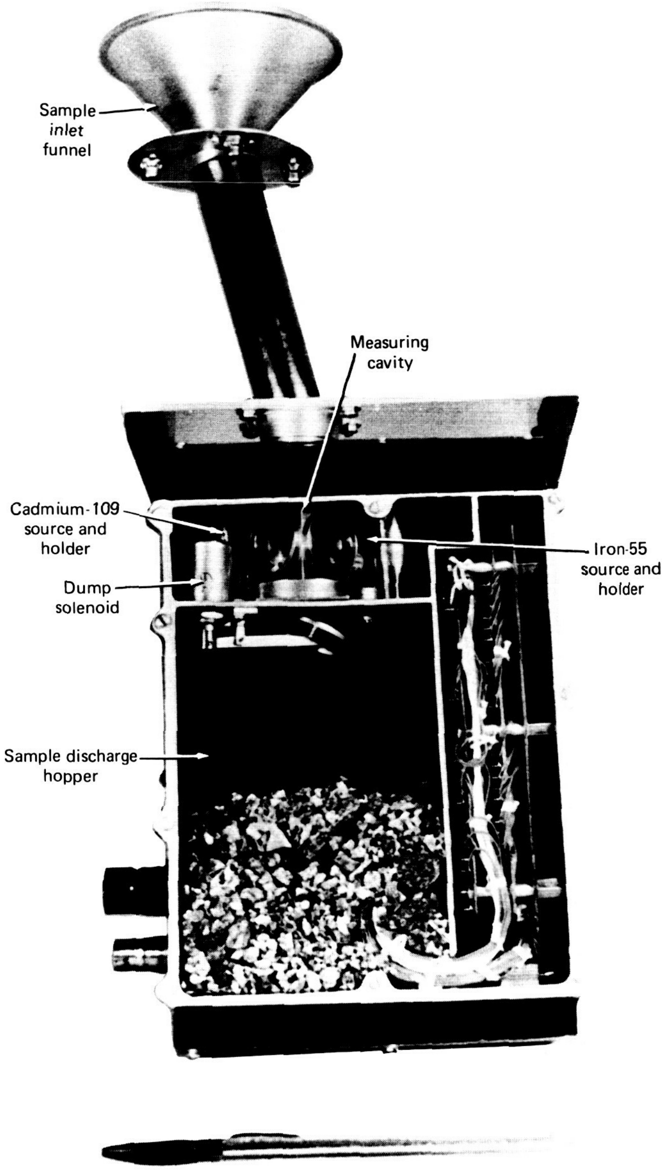


FIGURE 45.—X-ray fluorescence spectrometer.

X-rays in the fluorescence spectrum, we can calculate elemental abundances although not how they are incorporated into compounds, which has to be inferred. X-ray fluorescence is a common terrestrial analytical tool where materials must be identified without damaging the specimen.

On Viking a sample is dumped into the funnel shown in figure 45.

It falls into the measurement cavity where it is bombarded by the X-rays from radioactive iron-55 and cadmium-109. The X-rays that fluoresce from the sample are counted by four gas-filled proportional counters. The heights of the pulses delivered by the counter are proportional to the X-ray energies. A pulse-height analyzer sorts these pulses into an energy spectrum that is radioed back to Earth. The Viking instrument will detect elements with atomic numbers of 12 and higher. Each instrument cycle accepts up to 50 cubic centimeters of material from the Martian surface and analyzes it in about 5 hours.

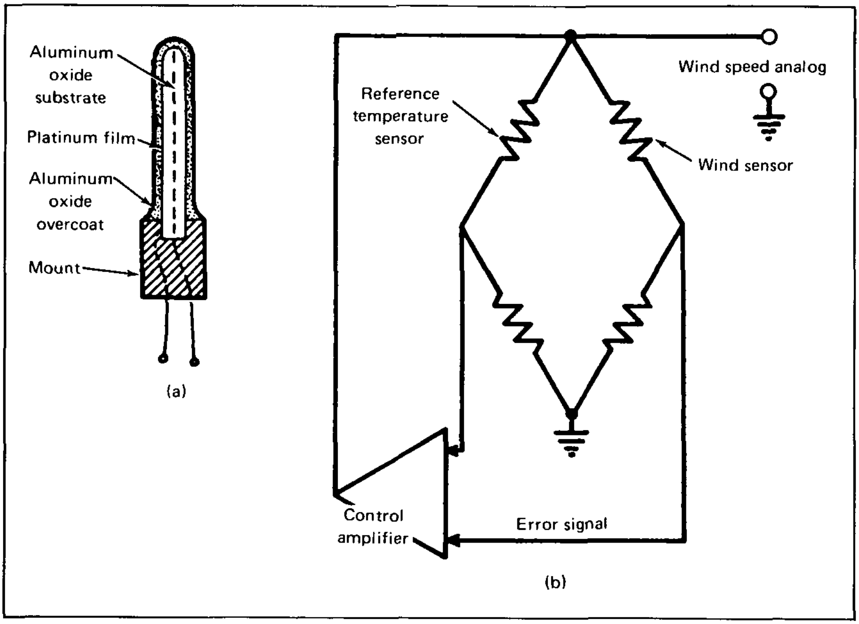


FIGURE 46.—Meteorology wind velocity sensor. (*a*) Probe. (*b*) Constant overheat circuit.

A Simple Martian Weather Station

Mars is now recognized as a meteorologically dynamic planet with sand dunes, cloud formations leeward of some mountains, and similar Earth-like phenomena. Scientists believe that Martian weather is a simple version of our own, and that we can learn a great deal by attaching a few simple meteorological sensors to the Viking Lander. Of course, the local weather will also be a factor in interpreting the other experiments. Frequent high winds would, for example, help geologists explain formations seen through the cameras.

Pressure, temperature, and wind velocity will be measured periodically throughout each diurnal cycle. The very low pressures of the Martian atmosphere (less than 1 percent of those on Earth) can be detected reliably with a stretched-diaphragm-type sensor. The thin metallic diaphragm forms one side of an electrical capacitor, with the exposed wall of an evacuated chamber forming the other. Any motion due to external pressure changes will be reflected as changes in electrical ca-

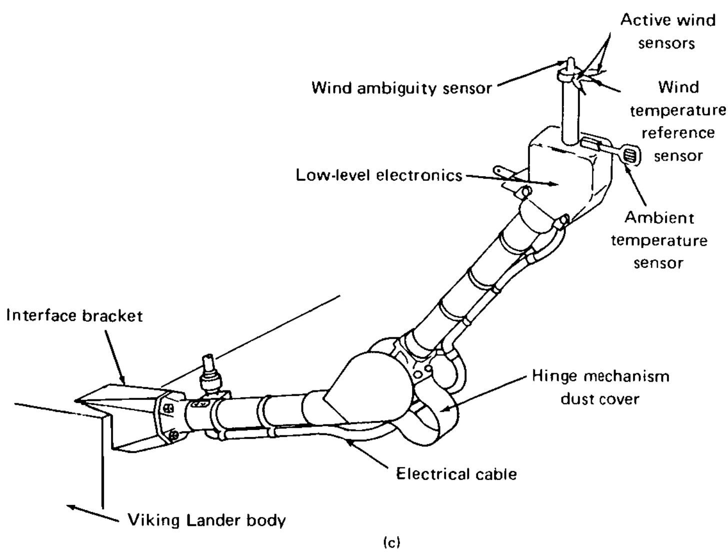


FIGURE 46.—Continued—(*c*) Boom with sensors.

pacitance. The diaphragm must be shielded from the wind, of course. Present plans are use the same pressure sensor employed during the entry phase.

Thin-wire thermocouples will measure the "air" temperature. These, too, must be behind a windshield. In fact, the wind velocity sensor is essentially a thermocouple exposed to the wind. It is called a "hot-film anemometer" and consists of an aluminum oxide cylinder or probe about 1 centimeter long (fig. 46) heated by electrical current passing through a thin platinum film. The higher the outside wind velocity, the more the probe is cooled. Windspeed is determined by measuring the electrical power required to keep the cylinder at a certain temperature with respect to a similar unheated probe. This kind of anemometer will be accurate to about 10 percent over the range between 2 and 150 meters per second (4.5 to 340 miles per hour). The hard aluminum oxide exterior protects the probe from the effects of sandblasting.

Marsquakes

From the vantage point of Mariner 9's cameras, Mars appears tectonically active. Motion of crustal plates should generate quakes and and microseisms. Monitoring these phenomena alone is sufficient reason for mounting a simple seismometer on the Lander frame. (The Apollo seismometers left on the Moon may completely change our view of the internal structure of the Moon.) A Martian seismometer could also register meteor impacts and perhaps determine whether Mars has a crust/mantle/core structure like the Earth.

The Viking seismometer is a small, three-axis instrument mounted on the Lander. Seismic vibrations will travel up through the Lander legs to the frame and thence to the seismometer. Three perpendicular components of ground motion are measured with the following sensitivities: 50×10^{-6} millimeter or less at 1 hertz and 1×10^{-6} millimeter or less at 4 hertz. During seismic quiet the seismometer will operate at a low data rate; however, a major quake will trigger a higher data mode, giving geologists a better look at the details of the vibrations as they propagate around and through the planet.

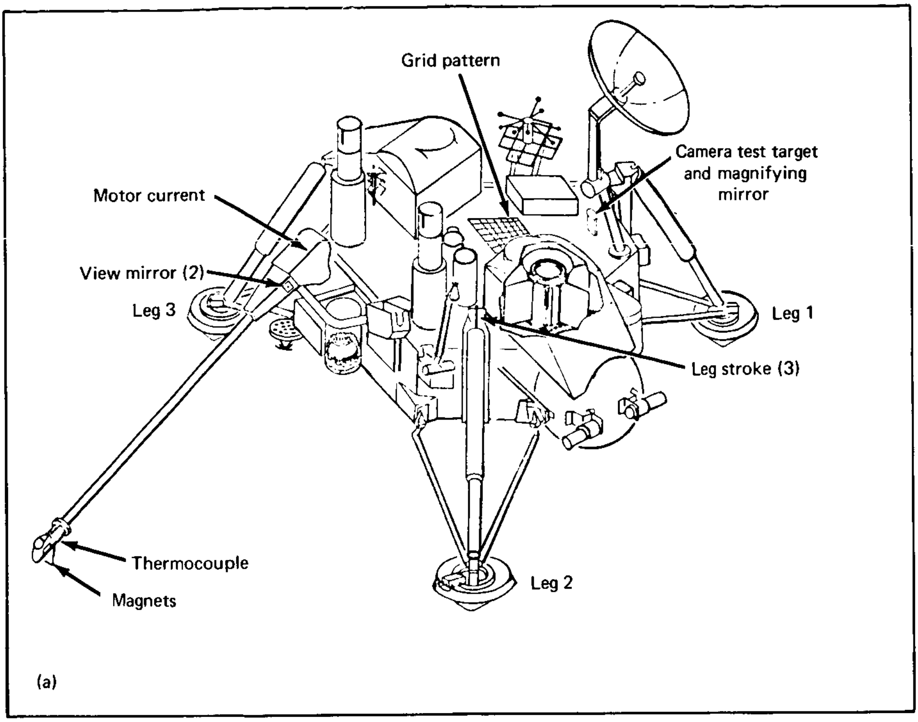
Does the Martian Soil Contain Magnetic Particles?

We know that the soils of Earth and the Moon contain several types of magnetic particles, some from eons of meteorite bombardment and others the result of geological processes. The presence of native iron, magnetite, limonite, and other iron-bearing materials can tell us something about the separation of minerals (differentiation) during the evolution of Mars and the oxidization of the surface in the distant past when the atmosphere of Mars presumably possessed oxygen.

Experience with the lunar Surveyors proved that small permanent magnets can detect magnetic particles in the soil. Simple visual inspection with a camera can lead to surprisingly accurate estimates of particle abundance. A logical place to mount magnets on Viking is directly on the head of the surface sampler (fig. 47). Every time a soil sample is collected, some of the magnetic particles will adhere to the magnet array. The sampler arm can be maneuvered around so that the magnet array can be photographed directly or via a magnifying mirror. Color pictures will help identify specific minerals. Magnets of different strengths and shapes in the array will add versatility. Additional magnets will be mounted on one of the Lander's camera calibration targets for the detection of windblown magnetic particles.

Physical Properties of the Martian Surface

Mars very likely has a surface layer of particles or soil much like Earth and the Moon. By observing the activities of the surface sampler with the cameras and the depth of the Viking Lander's footprint, engineers can deduce bearing strength, porosity, grain size, adhesion properties, and similar soil properties. In addition, Viking Lander telemetry



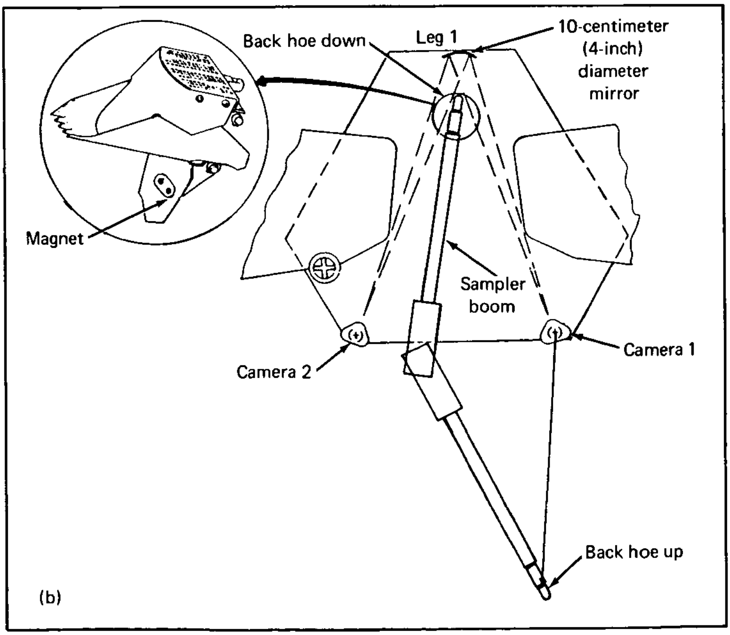


FIGURE 47.—Magnetic properties experiment. (*a*) Lander. (*b*) Enlarged view of placement of magnets.

will report on surface sampler motor currents and hence the resistance of the soil to the motion of the sampler head. The thermocouples located at various positions in the Lander to help assess the "health" of the spacecraft also can help determine the temperature and thermal inertia of the surrounding terrain.

Radio Experiments

Even if the Viking spacecraft carried only its radio transmitter and radars, with no scientific instruments whatever, the scientific return would be impressive. On Viking, as with most other deep-space and satellite flights, one will be able to extract considerable information from radio-tracking measurements and the properties of electromagnetic waves received from the spacecraft transmitters as they are modified by matter in space and Mars itself. Some of the planned investigations are—

(1) Tracking data will refine the orbit and mass of Mars.
(2) The Lander radars will measure the surface reflectivity in the microwave range.
(3) As the Viking Orbiter swings behind Mars, its radio signals will be distorted by the Martian atmosphere and ionosphere, leading to estimates of electron density in the ionosphere, etc.
(4) Lander-to-Orbiter transmissions will indirectly measure atmospheric turbulence.
(5) Precision tracking of the Orbiter (even from Earth) will yield estimates of atmospheric drag.
(6) The differences in propagation velocities of Viking radio signals at different frequencies (S-band and X-band dispersion) will provide a measure of electron concentration between Earth and Mars.
(7) Radio signal time delay caused by the Sun during superior conjunction will add greatly to our verification of Einstein's Relativity Theory.

Chapter 6
Touchdown on Mars

Viking at the Cape

Before the Orbiter, Lander, and launch vehicle meet at Cape Kennedy, they will already have passed a multitude of tests. These systems and the parts from which they are constructed will have been shaken, baked, and operated under simulated space conditions. Only acceptable parts survive the testing and screening procedures. Final checkout and assembly occur at NASA's Kennedy Space Center but these procedures will be far from routine. The Viking launch will be unique in that there will be two extremely complex systems making up the spacecraft rather than the usual one and the Lander will have to be "canned" and sterilized at the Cape.

The all-important sterilization of the Lander occurs in the Viking spacecraft assembly and encapsulation building. Sterilization is preceded by intensive cleaning and frequent bioassays to check the effectiveness of the cleaning steps. Immediately following encapsulation, the already well-cleaned Lander is then sterilized by baking for no more than 3 days at about 112° C. The next living matter it contacts may be of extraterrestrial origin.

All of these events have to be synchronized with the so-called "launch period" for Mars, which occurs about every 26 months. During this period, the Earth is just catching up with Mars as the two planets fly their elliptical courses around the Sun (fig. 12). Within this period there are daily launch "windows" when the propulsive requirements are low and well within the capabilities of the Titan III/Centaur. The daily window closes when the Titan III/Centaur can no longer propel the spacecraft into an interception course with Mars. During August and September 1975, a period of at least 41 days exists for Titan III/Centaur and the Viking spacecraft.

The Titan III solids alone (stage 0) lift the launch vehicle off the pad; the first Titan III liquid stage does not fire for approximately 2 minutes. After the Titan III second liquid stage cuts off, the Centaur upper stage injects the spacecraft into a parking orbit about 165 kilometers (90 nautical miles) above Earth. At precisely the right mo-

ment, an onboard guidance computer initiates the second firing of the Centaur rocket engine, which injects the spacecraft into a trajectory which will intercept Mars in the summer of 1976.

The Long Trip to Mars

During the 305- to 360-day cruise to Mars, the Viking Lander will be almost completely dormant and the Orbiter not much more lively. However, several very important things must be done. The first is to make sure that the spacecraft really does intercept Mars. If rocket angles and burn times are only slightly off during launch and the departure from parking orbit, the miss distance at Mars may be large. The Orbiter in conjunction with the DSN has the tasks of navigation and midcourse correction. First, the Orbiter opens its solar panels and performs a controlled search for the Sun using its inertial reference platform for spacecraft attitude reference. Then, it performs a roll search for the star Canopus. The DSN tracking antennas then acquire enough trajectory data to determine how much of a midcourse correction is needed. The Orbiter's engine then fires to nudge the spacecraft into a more accurate encounter trajectory. Up to three more midcourse corrections may be performed if needed.

During the long flight, the Orbiter will be tracked frequently (but not continuously) by the DSN. Housekeeping data will be recorded and scanned to determine the "health" of both Orbiter and Lander. Approximately every 15 days, the Orbiter will check out the Lander and carry out simple maintenance operations.

As the spacecraft trajectory begins to converge with the orbit of Mars, the Orbiter's scan platform and instruments are calibrated because they will be brought into play before the actual encounter. Approximately 10 days before encounter, the scan platform is unlatched and pointed toward Mars. Mars will still be tens of thousands of miles away, appearing as a small but rapidly increasing visible disk. The object of Viking preencounter science is to obtain global distributions of temperature and water vapor as well as pictures of the whole planet and its two moons for navigational purposes.

Encounter will occur between mid-June and late August 1976, when summer prevails in the northern hemisphere of Mars. As the spacecraft nears Mars, the Orbiter gas jets will swing the double spacecraft around so that the Orbiter engine is pointed roughly in the direction of flight. At command from Earth, the engine will burn for a little under an hour. The retrothrust reduces the spacecraft velocity by about 1480 meters per second and permits it to be captured by the gravitational field of Mars. The target orbit has a periapsis of 1500 kilometers (940 miles) above the Martian surface and an apoapsis of 32,600 kilometers (20,400 miles) and a period of 24.6 hours, the same time it takes Mars to rotate on its axis. If this rather eccentric ellipse is not obtained

precisely, the Orbiter's engine can "trim" the orbit, that is, adjust it to the desired shape (fig. 13). With this milestone, the real work of the Orbiter begins.

In Orbit About Mars

Orbiter's first task is to aid in final site selection. Prelaunch primary and backup landing sites have already been selected on the basis of Mariner 9 photos. The Viking Orbiter's cameras, water-vapor detector, and thermal mapping instrument will examine the sites in detail with an eye to scientific payoff and safe descent of the Lander. If the primary site looks risky, the Orbiter will begin examination of the backup site. Once the final selection has been made, the Orbiter's trim maneuvers will fix the orbit's periapsis right over the primary site.

Scientists would like a relatively warm, wet landing site with a thick soil layer. There should be formations of high geological interest nearby and no obstructions that would interfere with meteorological measurements. These objectives are in some degree incompatible. Warm, wet niches are likely to be at low elevations, perhaps at canyon bottoms. Unobstructed areas are likely to be featureless geologically and uninteresting biologically.

The engineers designing the Lander have an entirely different set of landing criteria:

(1) The spacecraft orbit fixes the site within the latitude band of 25° S to 75° N.
(2) The surface cannot be too rough or have too great a slope (more than 19°) or the landing will be endangered.
(3) The site must be at a low enough elevation to give the parachute enough dense atmosphere to slow the descent.
(4) The radars on the Lander require a surface with high microwave reflectivity for good, clear echoes.

After weighing the scientific and engineering factors, the Mission Director will make the final choice and give the go-ahead for landing. This decision should be made between 10 and 50 days after the spacecraft arrives at Mars.

Given a go-ahead for landing, the Orbiter attends to the task of reviving the dormant Lander. Preseparation checkout begins about 30 hours before the command is sent from Earth to sever the year-old mechanical and electrical ties between Orbiter and Lander. At separation, the Lander, which is already partially "uncanned," is separated from the Orbiter and the aft bioshield is discarded. The aeroshell's four small hydrazine engines are then ready to deorbit the Lander.

In scheduling orbital operations, it must be remembered that Viking A will be followed by Viking B, launched 10 to 41 days later. The goal here is to separate the spacecraft arrivals at Mars sufficiently to allow Lander A to get down to the surface and send back some engi-

neering and scientific data about the descent phase and the landing site itself. If Viking B is 10 or more days away from encounter when these data are received, its trajectory can still be modified enough to choose from a wide range of possible landing sites. Once in orbit, only small latitude changes but large longitude changes are possible due to the differences in energy required.

Descent to the Surface

Lander separation from the Orbiter is initiated by a command signal which energizes explosive nuts and allows compressed springs to separate the two vehicles. About 10 minutes later the aeroshell's four hydrazine engines fire and begin the deorbit maneuver. These engines in addition to four others for roll control are used to hold the Lander capsule in the proper attitude so that the cork-honeycomb ablative surface protects the capsule from heat and pressure and gives it a small amount of lift during entry. Between 2 and 5 hours after separation, the Lander encounters the sensible atmosphere at about 250 kilometers (800,000 feet). Peak deceleration occurs between 24,000 and 30,000 meters (80,000 to 100,000 feet; these figures are approximate because our knowledge of the Martian atmosphere is still limited) (fig. 14). By the time the spacecraft has penetrated to 6400 meters (21,000 feet) altitude, its velocity has decreased to about 375 meters per second (1230 feet per second). The parachute can be opened safely at this point. A few seconds later the aeroshell is separated via explosive bolt-compressed spring devices. (These and all other descent activities are carried out automatically by the Lander because it takes too long to transmit the pertinent atmospheric data to Earth and to return the appropriate command signal.) In about a minute the parachute-suspended Lander drifts down to 1200 meters (4000 feet) where it is falling at a rate of about 60 meters per second. Here, the Lander terminal-phase engines are ignited and the parachute is cut loose upon signal from the radar altimeter. Touchdown should occur at a vertical velocity of 2.44 meters per second (5.5 miles per hour). The entire sequence from atmospheric entry to touchdown takes between 6 and 13 minutes. In this short and very crucial span of time, all of man's knowledge of aerodynamics and the Martian atmosphere must be brought to bear. If successful, we will have soft landed our first cargo of scientific instruments on another planet of the solar system.

Lander Operations Begin

Once safely on the surface, the Lander's first order of business is the establishment of communication links with the Orbiter and with the DSN antennas on Earth. Neither link is continuous because Mars rotates on its axis and the Orbiter's position relative to the Lander precesses slightly (fig. 48). Once again, we have time windows. The ultrahigh frequency Orbiter relay link window is open when the Lander sees the

Orbiter 25° or more above the horizon and within 5000 kilometers. This window will be open for between 10 and 40 minutes once a day. The window governing the direct radio link to Earth is open for about 12 hours a day, but can be used only when the Lander's high-gain antenna can contact a DSN 64-meter dish. Lander electrical power limitations restrict radio communication to 2 hours a day.

Early in the mission, the direct link to Earth can transmit about 3.6 million bits of information during the daily 2-hour window. As the Mars/Earth distance increases, the rate decreases to 1.8 million bits daily. The ultrahigh frequency link to the Orbiter can carry up to 16,000 bits per second, compared to a maximum of 500 bits per second direct to Earth. The relay link window, however, is not open as long, and the maximum number of bits per day will be about 38 million. Although

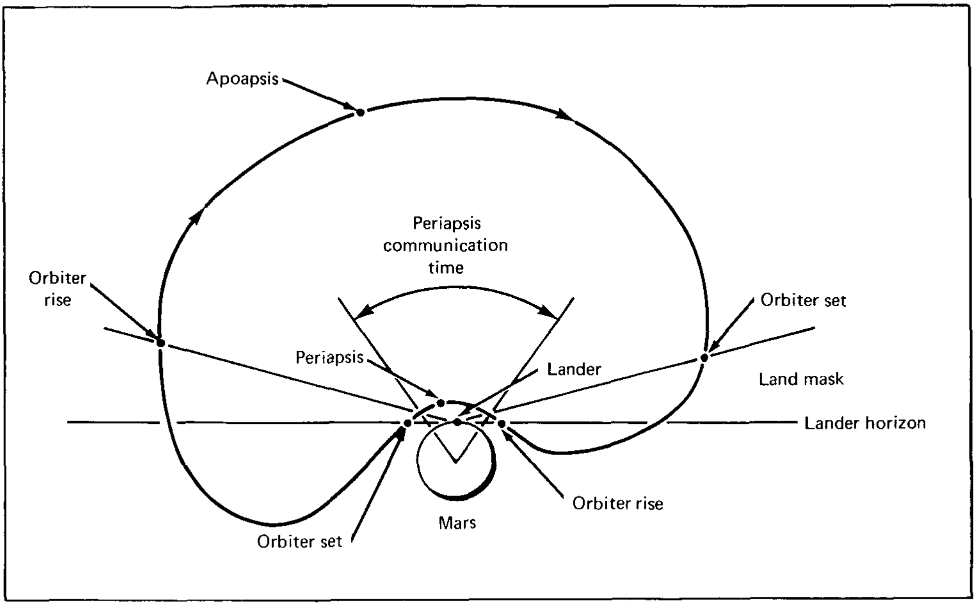


FIGURE 48.—Lander-to-Orbiter communication geometry.

these numbers sound very large, the Lander cameras can consume as many as 10 million bits per picture. Other instruments are less voracious in terms of bits. Obviously, priorities have to be established for the instruments.

Operating plans, too, must be carefully formulated. The present plan is to keep Orbiter A with its periapsis over the site of Lander A for a complete scientific cycle—about 22 days. While relaying Lander A's data to Earth, Orbiter A will survey potential landing sites for Lander B, some 7 weeks behind the Viking A schedule. If the promising Viking B

sites are too far away from Orbiter A's orbit, it may be commanded to break off its support of Lander A and begin reconnoitering sites for Lander B. When Viking B arrives and its Lander is successfully soft landed, many options become possible. Orbiter A may act as a relay for Lander B, and Orbiter B may act as a relay for Lander A. Or, one Orbiter may be delegated to serve both Landers while the other begins scientific missions on its own. (Orbiter design life is 140 days after attaining orbit. The Lander design life after landing is 90 days.) This flexibility will be invaluable should trouble develop with any of the spacecraft. This pairing of spacecraft and communication links and the large-scale redundancy of spacecraft components yield a high probability of success for the Viking mission as a whole, even if one of the spacecraft should fail completely. A scientific bonus also results from joint Orbiter-Lander operations in that the Orbiter can prepare the Lander for oncoming atmospheric disturbances and then observe the phenomena from orbit while the Lander takes *in situ* measurements.

Chapter 7
The Viking Team

The Viking project involves thousands of people building and operating complex machines to achieve specific objectives within a certain timespan for a given number of dollars. Viking differs from other large technological enterprises mainly in the hundreds of millions of miles between its radio-connected systems and in its scientific objectives—the exploration of another planet of the solar system.

The human organization of the Viking project parallels the organization of the machine; that is, each major Viking system has a "people counterpart." As illustrated in figure 49, the six Viking systems are split neatly in two: three systems of flight hardware and three ground-based systems which are manned by human controllers who communicate with and command the flight hardware. Here we get into the realm of management, with its organization charts, contractors, schedules, etc.

Overall program management begins at NASA Headquarters, Washington, D.C., in the Office of Space Science. The major portion of the management task is delegated to NASA's Langley Research Center, located at Hampton, Va. Langley's Viking Project Office, consisting of about 250 engineers and scientists, directs the day-to-day progress of the program. NASA Headquarters has assigned responsibility for the six Viking systems in the following way:

(1) *Lander system.*—Langley's Viking Project Office oversees Martin Marietta Aerospace's Denver Division, the contractor responsible for designing and building the Lander.

(2) *Orbiter system.*—The Jet Propulsion Laboratory has the responsibility for designing and building the Orbiter.

(3) *Launch vehicle system.*—Responsibility for this system has been assigned to NASA's Lewis Research Center. Martin Marietta Aerospace builds the Titan III booster while the Centaur stage is a product of General Dynamics Corp.

(4) *Launch and flight operations.*—Langley's Viking Project Office manages this operational system with design and implementation by Martin Marietta Aerospace, the Jet Propulsion Laboratory, and the Kennedy Space Center. Kennedy Space Center is responsible for conducting the actual launches at the Cape.

(5) *Tracking and data system.*—The DSN, built and operated by the Jet Propulsion Laboratory under the sponsorship of NASA, is the only U.S. network capable of tracking and communicating with spacecraft as far away as Mars. The Jet Propulsion Laboratory has management responsibility for this system. Ground communication, i.e., transmission of data from radio stations to control center, is achieved via landlines. The NASA Goddard Space Flight Center is responsible for this function.

(6) *Mission control and computing center system.*—The Jet Propulsion Laboratory's SFOF is equipped with the computers and displays needed for directing interplanetary missions. Responsibility for this system is assigned to the Jet Propulsion Laboratory.

So far, the organization of the Viking project follows traditional lines: The flight hardware is divided into handy systems and assigned to specific operation components of NASA and associated industrial contractors. Systems incorporating the ground-based hardware and the incredible amount of software (computer programs) have been assigned to "systems managers." When it comes to science—which is what Viking is all about—there has been a distinct departure from tradition. Most

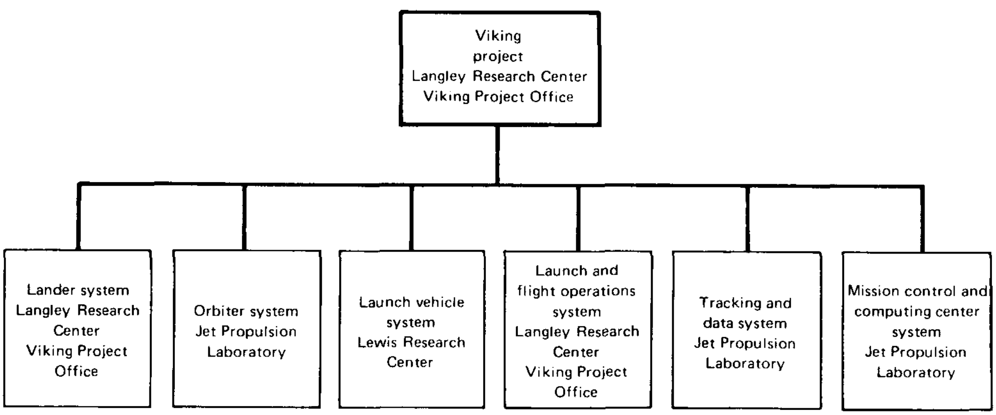


FIGURE 49.—Viking project structure.

NASA space science to date has been organized around principal investigators, individual scientists who propose a specific study, develop an instrument for flight, analyze data received, and publish results. Viking instead makes use of individual scientific teams. Each team has a leader who represents the team to the Viking project, but the scientists in each team participate on an equal basis.

Most of the scientific instruments are on the Lander. The associated science teams are—

(1) Imaging
(2) Seismology
(3) Molecular analysis
(4) Biology
(5) Entry
(6) Magnetic properties
(7) Meteorology
(8) Inorganic chemical
(9) Physical properties

The Orbiter is also an instrument carrier and has the following science teams assigned:

(1) Imaging
(2) Water vapor mapping
(3) Thermal mapping

Lastly, a radioscience team, which uses the Orbiter and Lander radio signals, has been formed to study the properties of interplanetary space, celestial mechanics, and the Martian atmosphere by means of their effects on radio signals transmitted back to Earth or their perturbations of the spacecraft.

* * *

Viking will be the beginning of a new phase of man's exploration of the unknown. He will put his machines softly onto the surface of another planet and by remote control begin to study the very essence of that planet. He will try to determine the imprint of life on that planet (or its absence) and thereby to determine by analogy the place of his own planet and its life forms in the universe. If life exists, he will have created a new science of biology, based on a completely new set of data. If life does not exist he will have a new approach to understanding the problems of the Earth induced by its overwhelming biota; that is, he will have the comparison of a planet evolving in the absence of life. In either case, man is the winner because he will be closer to viewing his place in the Sun.

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★ U.S. GOVERNMENT PRINTING OFFICE: 1974 O—552-763